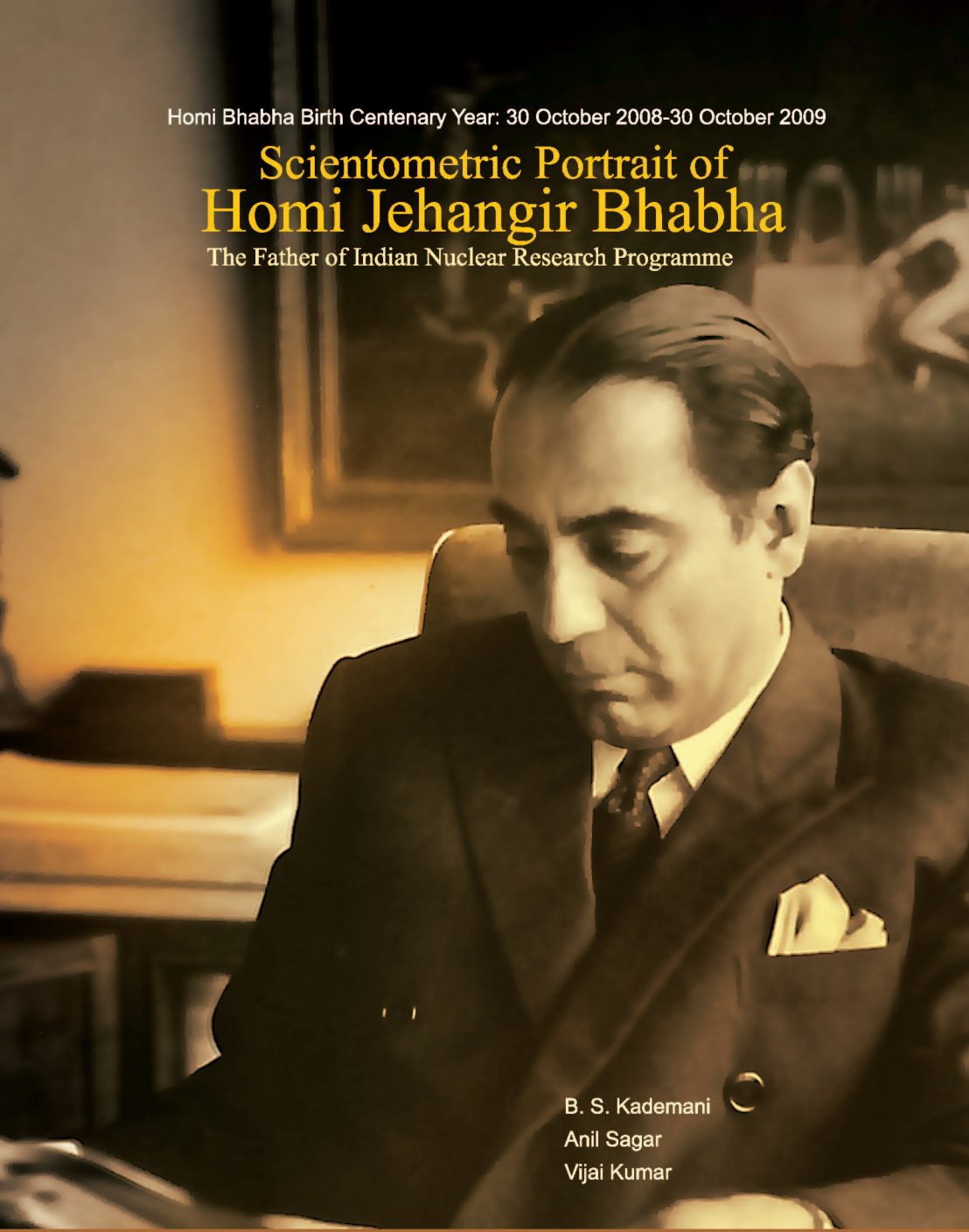
Homi Bhabha Birth Centenary Year: 30 October 2008-30 October 2009

Scientometric Portrait of Homi Jehangir Bhabha

The Father of Indian Nuclear Research Programme



B. S. Kademani
Anil Sagar
Vijai Kumar

Scientific Information Resource Division
Knowledge Management Group
Bhabha Atomic Reserarch Centre
Mumbai - 400 085, India
2009

Portrait of Prof.P.M.S Blackett .
Sketched by H.J. Bhabha

Homi Bhabha Birth Centenary Year: 30 October 2008-30 October 2009

Scientometric Portrait of Homi Jehangir Bhabha

The Father of Indian Nuclear Research Programme

B. S. Kademani
Anil Sagar
Vijai Kumar

Scientific Information Resource Division
Knowledge Management Group
Bhabha Atomic Reserarch Centre
Mumbai - 400 085, India
2009

PREFACE

It gives us immense pleasure in bringing out this booklet 'Scientometric Portrait of Homi Jehangir Bhabha : The Father of Indian Nuclear Research Progrmme' on the occasion of the celebration of Homi Bhabha Birth Centenary Year :30 October 2008 – 30 October 2009.

Bibliometrics is a method used to analyse and quantify the bibliographic data. It offers a powerful set of methods and measures for studying the structure and process of scholarly communication. Scientometrics is the Russian term for application of these methods and measures which are dealing with the analysis of science. Bio-bibliometrics is a quantitative and analytical method for discovering and establishing functional relationships between bio-data and biblio-data elements. 'Scientometric Portrait' is a phrase used to carry out bio-bibliometric studies on scientists rather than academicians or researchers from other disciplines such as arts, humanities and social studies. With the advent internet the interest of researchers in this field turn to the measurement of webpages or websites, new terms such as webometrics, cybermetrics and netometrics have been coined to describe the application of measurement techniques to the internet, web and cyberspace pages or sites.

Homi Jehangir Bhabha was a multifaceted personality- a scientist, an artist, and an institution builder. We focus on the quantitative and qualitative aspects of Homi Jehangir Bhabha's scientific works in this booklet. An attempt has been made to highlight the topics on which Bhabha worked and the influence of Bhabha's scientific works on other areas of science by way of citation analysis. We also identified the 'Highly Cited' papers of Homi Jehangir Bhabha. We sincerely hope this booklet brings to you the scientific edifice of Homi Jehangir Bhabha.

We would like to place on record the excellent help rendered by Shri Bhushan Chavan, SIRD in formatting the text and cover design.

SIRD, BARC

B. S. Kademani

October 30,2009

Anil Sagar

Vijai Kumar

CONTENTS

Scientometric Portrait of Homi Jehangir Bhabha

The Father of Indian Nuclear Research Programme

INTRODUCTION

Individuals are the source of ideas. The institutions are built by the individuals and grow around individuals. Individuals are the basic foundations of any institution. By studying the individuals who have reached the top positions in academic and research life and by highlighting their works may throw some light on how the dynamics of science works and may stimulate the younger generation to emulate and create scientific temper among them.

Research is a complicated process involving very often a large number of intricate issues, and evaluation of scientific activity is still more complicated. Evaluation is a very important component of any research and development activity in an institution. Results of evolution of science have become major parameter for those dealing with decision making for the management of science. One of the first writers to suggest number of research papers as a scientific measure of research productivity was Nobel laureate William Shockley (1957). Martin and Irvin (1983) have thoroughly reviewed about the basic research inputs and outputs and various possible assessment methods. They also considered the count of scientific publications and citations, and peer evaluation methods providing characteristic indicators. Publication and citation counting techniques have been used in the assessment of scientific activity for at least fifty years. During the half-century of this activity the main thrust of interest seems to flow along two connected but parallel paths: the bibliometric path of publication and citation counts as tools for the librarian, and an evaluative path using these same tools to

illuminate the mosaic of scientific activity (Narin, 1976). Laharia and Singh (1987) have discussed various approaches used to measure the scientific productivity and Lancaster (1991) has suggested bibliometric measures of productivity and impact in research.

Scholars use all kinds of signals to distill the value of a book or an article. To name a few: the reputation of the publisher or the editorial board of a journal, the author's institution and the number of citations the article has received (Van Dalen and Henkens, 2005).

Citation brings out the connection between two documents; the one which cites and the other which is cited. The act of citing in general, an expression of the importance of the material cited, as authors often refer to previous material to support, illustrate or elaborate on a particular point (Garfield, 1978, 1994). A highly cited work, naturally, is the one that has been found to be useful by relatively large number of authors, or in relatively large number of experiments. Citation count is, therefore, a measure of scientific activity, utility and impact of scientific work. However, citation counts do not say anything about the nature, utility or impact of the work (Garfield, 1979).

Citation analysis constitutes an important tool in quantitative studies of science and technology. To assess the quality of a given publication, the number of times it has been cited in the literature can be counted. Similarly, the number of times a person has been cited in the literature can be taken as a measure of the quality of that person's work (Garfield, 1979, 1994; Lawani, 1977; Moravcsik, 1976; Narin, Carpenter and Woolf, 1983; Smith, 1981; Wallmark and Sedig, 1986). Citation analysis is a more complex task than is often recognized in the sense that it requires careful identification of exactly what is being analysed. Every citation represents a decision of the author to draw attention to the work of another as being relevant to his theme at a particular point in the document he is writing (Sandison, 1989).

Citation counts not only help a research administrator to assess the quality of each individual scientist but also that of his organization as a whole. A few scientometric studies on Nobel laureates (Cawkell and Garfield, 1980; Gupta, 1983; Kragh, 1990; Kademani, Kalyane and Kademani, 1994; Kademani, Kalyane and Kademani, 1996; Kalyane and Sen, 1996; Sri Kantha, 1996; Kalyane and Kademani, 1997; Kademani, Kalyane and Jange, 1999; Kademani, Kalyane and Vijai Kumar 2001; Kademani, Kalyane and Vijai Kumar, 2002a; Kademani, Kalyane and Vijai Kumar, 2002b; Angadi, et al., 2004; Koganuramath, et al., 2004; Kademani et al., 2005; Angadi, et al., 2006; Angadi, et al., 2007) and eminent scientists (Gupta, 1978; Ruff, 1979; Gupta and Gupta, 1983; Dieks and Slooten, 1986; Goldstein, 1990; Todorov and Winterhager, 1991; Lancaster, Zeter, and Metzler, 1992; Lancaster, Bushur, and Man Low, 1993; Kademani, Kalyane and Balakrishnan, 1994; Kademani, Kalyane and Kademani, 1994; Kalyane and Kademani,1995; Kademani and Kalyane, 1996a; Kademani and Kalyane, 1996b; Kademani, Kalyane and Kademani, 1996; Kademani and Kalyane, 1998; Tiew and Wai Sin, 1999; Kademani, Kalyane and Vijai Kumar, 2000; Kalyane, Madan and Vijai Kumar, 2001; Rushton, 2001; Mabe and Amin, 2002; Kalyane and Sen, 2003; Muddiman, 2003; Sangam, et al., 2006; Kademani and Anil Sagar, 2007; Kademani, Kumbar and Surwase, 2008; Swarna et al., 2009) have been conducted all over the world. These studies have indicated that it is possible to develop a model on the performance of a 'Role Model' scientist of a country that has a direct bearing on the identification of promising scientists and human resource development in developing countries. Individual scientist, including Nobel laureate, is the current focus of scientometric studies.

The unit of study in citation analysis can be any form of written communication or an author, an organization or a nation (Small and Greenlee, 1979). However, citation counts cannot be taken as the sole measure of quality, because numerous other factors affect scientists' work and the impact of their publications is only a measure of their overall influence. For instance,

a scientist who spends most of his time on teaching may contribute in an indirect way to the future achievements of his institution. Sometimes a scientist may require years of background work to prepare a paper and that single paper itself would be a vital contribution having more value than that of publications of other prolific authors. Nevertheless scientists themselves are almost invariably keen to see this kind of information (Martyn, 1975; Cronin, 1984; Mac Roberts and Mac Roberts, 1989; Brown, 1993; Mahajan, 1993). One should be very careful while collecting and carrying out citation analysis as it may contain some discrepancies (Garfield, 1977; Moed and Vriens, 1989). Liu (1993) reviewed on the citation studies that have dealt with citation functions, quality, concept and motivation. Citation analysis as a subject remains controversial (Taube, 1993). Rousseau (1995) proposed a framework within which citations can be used for evaluation purposes.

BRIEF BIOGRAPHICAL ACCOUNT OF HOMI JEHANGIR BHABHA

Homi Jehangir Bhabha was born in a rich Parsi family in Mumbai on 30th October 1909. He had his early education at Cathedral and John Connon Schools, Elphinston College and Institute of Science, Mumbai up to the age of seventeen. Young Bhabha was constantly surrounded by works of high culture, music, paintings and books. Bhabha's father Jehangir Bhabha and uncle, Sir Dorab Tata, wanted him to study for an engineering degree. They expected that he could take over ownership of the Tata Iron and Steel Company at Jamshedpur. So he joined Caius College Cambridge in 1927. Bhabha influenced by physicists like Paul Dirac, his interests were drawn toward the theoretical physics. In a letter to his father in 1928, he described his profound love for physics :

> 'I seriously say to you that business or job as an engineer is not the thing for me. It is totally foreign to my nature and radically opposed to my temperament and opinions. Physics is my line. I know I shall do great things here. For, each man can do best and excel in only that thing of which he is

> passionately fond, in which he believes, as I do, that he has the ability to do it, that he is in fact born and destined to do it . . .Besides India is not a land where science cannot be carried on. I am burning with a desire to do physics. I will and must do it sometime. It is my only ambition. I have no desire to be a "successful" man or the head of a big firm. There are intelligent people who like that and let them do it . . . It is no use saying to Beethoven "You must be a scientist for it is great thing" when he did not care two hoots for science; or to Socrates "Be an engineer; it is work of intelligent man." It is not in the nature of things. I therefore earnestly implore you to let me do physics'.

Bhabha's father agreed to his wish to take up the mathematics Tripos-on the Condition that he should first complete the Mechanical Tripos successfully. This, Bhabha did. He obtained Mechanical Sciences Tripos in First Class in June 1930 and thereafter went on to work as a research student in theoretical physics. Bhabha completed his Ph.D. from Cambridge under the guidance of R.H. Fowler in 1935. He worked in the company of great scientists like John Cockroft, P. M. S. Blackett, Cecil Powell, Wolfgang Pauli, Enrico Fermi, P. A. M. Dirac, Neils Bohr, Gregor Wentzel and others.

Bhabha wrote his famous paper on relativistic electron-positron scattering including exchange, now known as 'Bhabha Scattering" when he was in Zurich. Bhabha had a tough time to convince Wolfgang Pauli to get his paper recommended. Finally Bhabha had to take the help of Gregor Wentzel, another well known scientist to get the paper recommended by Pauli (Freund, 2007).

When the Second World War broke out in 1939, Bhabha came to India on a holiday and remained in India thereafter. He spent nearly five years in Indian Institute of Science under C.V. Raman as reader in Theoretical Physics.

He was elected fellow of the Royal Society in 1941. He became Professor of Cosmic Ray research in 1942 and the elected president of the Physics Section of the Indian Science Congress in 1943.

Bhabha was mainly responsible for the establishment of Tata Institute of Fundamental Research (TIFR) and Bhabha Atomic Research Centre (BARC) (Formerly Atomic Energy Establishment Trombay (AEET)) and other DAE Institutes. TIFR was the cradle of India's atomic energy programme as the initial research programmes started here.

Bhabha presented a paper titled 'world energy requirements and the economics of nuclear power with special reference to underdeveloped countries' in the Third United Nations Conference on the Peaceful Uses of Atomic Energy, held at Geneva in September 1964.

Bhabha's stay in Cambridge and visit to many art galleries and museums of Europe had a great impact on him which is evident from his several sketches (Bhabha, 1968).

Bhabha held many positions in different capacities and received many honours and awards including Padma Bhushan (1954) in recognition of his outstanding contribution in the field of Nuclear Science and Technology. In 1955 Bhabha was elected as the president of the First International Conference on the Peaceful Uses of Atomic Energy organized by the United Nations at Geneva. Many foreign and Indian Universities have conferred honorary doctorates on him.

Bhabha was an Institution builder, painter, musician, educationist and an able administrator. He died in a tragic air-crash on Mont Blanc on 24th January 1966. Bhabha's multifaceted personality has been portrayed by many and well documented (Cockcroft and Menon, 1967; Penney, 1967; Kulkarni and Sarma, 1969; Anderson, 1975; Sreekantan, Virendra Singh

and Udgaonkar, 1985; Venkataraman, 1994; Parthasarathy, 2003; Deshmukh, 2005; Havanur, 2006; Subbarayappa, 2007; Wadia, 2009).

BHABHA CHRONOLOGY (1909-1966)

1909	October 30th Born in Mumbai (then Bombay)
1924	Passed Senior Cambridge leaving examination studied in Elphinstone College and Royal Institute of Science (since underage for Cambridge University)
1925-27	Studies in Elphinstone College and the Royal Institute of Science (since he was underage for Cambridge University)
1927	October, joined Gonville and Caius College, Cambridge, England
1930	Graduated in Mechanical Science Tripos; B.A. (Cantab) (First Class)
1931-32	Salomons Studentship in Engineering
1932	Mathematics Tripos (First Class), Rouse Ball Travelling Studentship in Maths, Cambridge; Visited Copenhagen and Zurich
1933	Isaac Newton Scholarship for his first research paper
1935	Received his Ph.D. in Theoretical Physics from Cambridge University. The title of his thesis was "On Cosmic Radiation and the Creation and Annihilation of Positrons and Electrons". His guide was Sir Ralph Fowler, Physicist & Astronomer who also guided S. Chandrasekkar, Paul Dirac and D. R. Hartree.
1936	Senior Studentship of the Exhibition of 1851; Bhabha-Heitler Theory-letter in Nature in July
1937	Bhabha-Heitler Cascade Theory of Cosmic Ray Showers-27 page article in Proceedings of the Royal Society
1939	Stranded in India as World War II begins; In a short note in Nature, was the first to suggest name "Meson" for a new particle found in Cosmic Radiation; Joined as Reader in

	Theoretical Physics at the Indian Institute of Science (IISc), Bangalore
1940	Special Reader in Cosmic Ray Physics, IISc., Bangalore
1941	Elected Fellow of the Royal Society, London
1942	Adam's Prize, Cambridge University Full Professor, Cosmic Ray Research Unit, IISc., Bangalore
1943	Sectional President, Physics, 30th Indian Science Congress, Kolkata.
1944	March 12, Letter to the Sir Dorabji Tata Trust
1945	June 1, Foundation of TIFR; First Director, TIFR
1946	Member, Atomic Research Committee, CSIR
1947	August 26, Chairman, Board of Research on Atomic Energy
1948	August 10, Chairman of the newly established AEC, India; Hopkins Prize of the Cambridge Philosophical Society
1951	General President, 38th Indian Science Congress, Bangalore
1954	Padma Bhushan; Secretary to Govt. of India, DAE; Founding Director, AEE
1955	President, First International Conference on Peaceful Uses of Atomic Energy
1956	August, Apsara swimming pool reactor becomes critical
1957	Training School established at AEET; President, National Institute of Sciences, India (NISI); Elected Honorary Fellow of the Royal Society of Edinburgh, England; Elected Honorary Fellow of Gonville and Caius College
1959	Elected Honorary Fellow of the American Academy of Arts and Sciences
1960	CIRUS reactor becomes critical
1961	ZERLINA reactor becomes critical; Space research started under DAE
1962	January 15, new building of TIFR inaugurated
1963	Appointed Chairman, Electronics Committee; Tarapur Atomic Power Station agreement with the USA signed; Elected a

	foreign associate of the National Academy of Sciences of the USA
1960-63	President, International Union of Pure and Applied Physics
1964	Tarapur construction started
1965	Plutonium Plant at Trombay inaugurated; Electronics Committee Report finalised.
1966	January 24, Death over Mont Blanc, Alps in the crash of Air India's plane Kanchanjunga.

OBJECTIVES

The main objective of the study reported in this article, is to highlight the quantitative and qualitative aspects of Bhabha's publications:

- to find out year-wise growth of publications and citations,
- to find out time-lag between publication of a paper and its receiving first citation,
- to identify extent of citations received to the publications of H. J. Bhabha,
- to find out domain-wise distribution of publications and citations,
- to differentiate the citation pattern with his position in authorship of the cited publications,
- to find out core collaborators of H. J. Bhabha,
- to identify core citing peer group,
- to identify highly cited publications of H. J. Bhabha
- to ascertain the preference of communication channels preferred by H. J. Bhabha and characteristics of citing documents,
- to find out distribution of citing journals according to country and impact factors, and
- Documentation of keywords appeared in the titles of Bhabha's publications and key words in the citing publications.

MATERIALS AND METHODS

The bibliographic details of research publications of H. J. Bhabha were collected from the Collected Scientific Publications of H. J. Bhabha brought out by B. V. Sreekantan, Virendra Singh and B. M. Udgaonkar, 1985 and the compilation brought out by the TIFR Library, 1980 formed the basic material for this study. All the publications (104) were searched for citations as per Web of Science (1933-2008). Web of Science is an online database service provided by Thomson Reuters. It provides access to seven databases: Science Citation Index (SCI), Social Sciences Citation Index (SSCI), Arts & Humanities Citation Index (A&HCI), Index Chemicus, Current Chemical Reactions, Conference Proceedings Citation Index: Science and Conference Proceedings Citation Index: Social Science and Humanities. Its databases cover almost 10,000 leading journals of science, technology, social sciences, arts, and humanities and over 100,000 book-based and journal conference proceedings. It provides retrospective coverage since 1900. The data obtained were then transferred to spread sheet application and analysed as per objectives of the study.

RESULTS AND DISCUSSION

Year-wise Growth of Publications and Citations

H. J. Bhabha had published a total of 104 publications which include 69 Journal articles, 21 Conference papers, 12 Speeches, 1 Meeting and 1 Biographical item during 1933-1967 in various domains: Interaction of Radiation with Matter (4), Quantum Electrodynamics (5), Mathematical Physics (2), Cosmic Ray Physics (18), Elementary Particle Physics (14), Field Theory (15), General Physics (2), Nuclear Physics (4) and General (40). H. J. Bhabha published his first paper in Nature in 1933 at the age of 24 in the domain Interaction of Radiation with Matter for which he was awarded the Newton Studentship. He subsequently published 103 publications in various domains. The last paper was published in collaboration with Kathleen in

1967 a year after his tragic death, a Biographical Memoir on K. S. Krishnan. The highest numbers of publications (6) were published in 1941, 1945 and 1964 respectively. The average number of publications published per year was 3.05. The productivity coefficient was obtained by the simple formula- 50 percentile age per total productivity age (Sen and Gan, 1990). His productivity coefficient was 0.50 which is a clear indication that his publication productivity was steady throughout the period. Figure-1 gives year-wise growth of publications and citations.

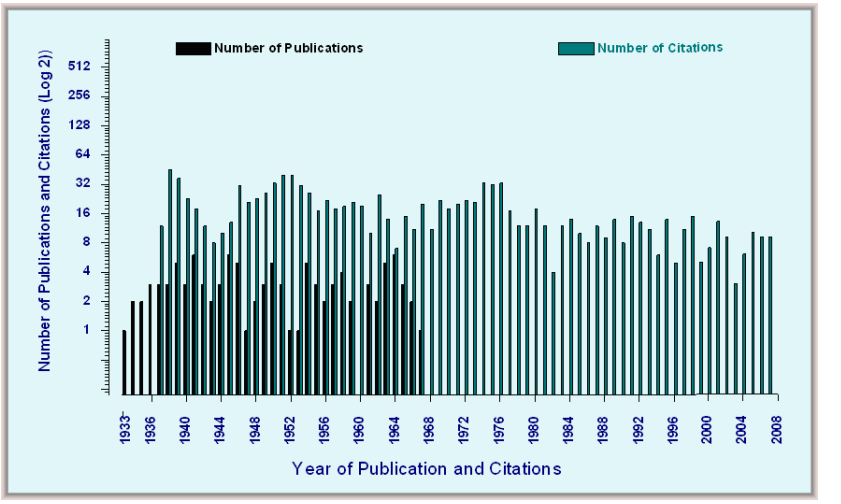


Figure 1: Year-wise Growth of Publications and Citations

Out of 104 the publications of Bhabha only 30 publications received citations. These 30 publications have received a total of 1211 citations during 1933-2008. Bhabha became a citable author in 1937. The average number of citations per year was 16.81. The average number of citations per publication was 17.55 (only journal articals (69 Nos.) were considered). The highest numbers of citations received were 45 in 1938. The publications continue to receive citations till 2008

indicates the relevance of H. J. Bhabha'spublications. Figure-2 presents year-wise growth of citations: self-citations, citations by others and

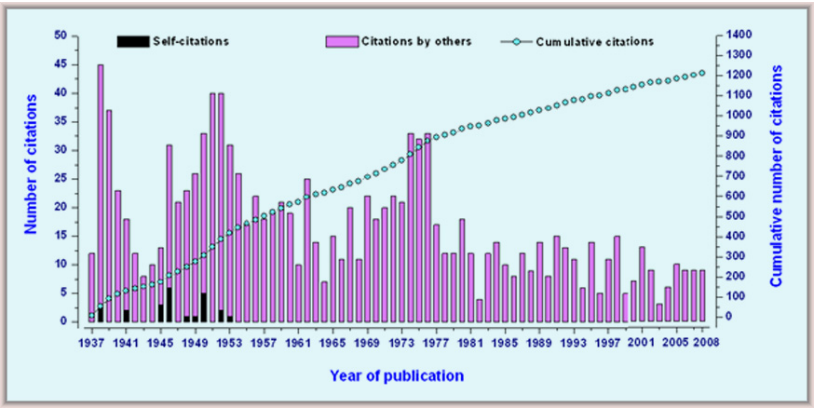


Figure 2: Year-wise Growth of Citations to H. J. Bhabha's Publications

cumulative citations to H. J. Bhabha's publications. Total self-citations were 24 (1.98%) and citations by others were 1187 (98.02%). The highest numbers of self-citations were six in 1946. The highest number of citations by others were 43 in 1938. Mean diachronous self citation rate was 1.98 (n=30). Lawani (1982) has defined diachronous self-citation rate as follows. Table-1 gives the number of publications and their citedness.

$$\text{Diachronous Rate} = \frac{\text{Self Citations to an Article in WoS Database}}{\text{Total Number of Citations Received to an Article in WoS Database}} \times 100$$

There is always some percentage of papers remain uncited for variety of reasons. The contents of the papers may be ahead of time and beyond the grasp of contemporary scientists, important paper published in an obscure journal, etc. Ghosh and Neufeld (1974) have studied the uncitedness of articles in the Journal of American Chemical Society and found that only 14.7 per cent were not cited during any given year. Ghosh (1974) has

also studied the uncitedness of articles in the multidisciplinary scientific journal Nature and found that an average of 48.6% of the test papers from Nature were uncited. Stern (1990) has conducted a study to determine the bibliographic characteristics of uncited papers in biomedical literature and found that certain bibliographic characteristics differentiate cited from uncited papers. In a typical study Kademani

Table 1: Distribution of H. J. Bhabha's Publications on the Basis of Citedness

Number of Citations	Number of Publications	Total number of Citations	Cumulative no. of citations
0	74	0	0
1	3	3	3
3	1	3	6
5	1	5	11
7	1	7	18
8	2	16	34
12	2	24	58
13	1	13	71
14	1	14	85
18	1	18	103
22	1	22	125
26	2	52	177
27	1	27	204
28	2	56	260
34	2	68	328
35	1	35	363
40	1	40	403
48	1	48	451
70	1	70	521
102	1	102	623
109	1	109	732
141	1	141	873
149	1	149	1022
189	1	189	1211
Total	104	1211	-

and Kalyane (1996b) have compared thirteen papers considered by a scientist as most significant with citations received to these publications and found that four papers were outstandingly cited, four were remarkably cited, one was fairly cited, one paper was poorly cited and two papers were uncited. This indicates that self assessment by a scientist, about the significance of his papers may not always tally with the world opinion. Sharma and Sen (2005) have stated that it is very difficult to find out the reasons for uncitedness for significant contributions as there is no easy mechanism available other than through citations.

Citation Time-lag

Citation time-lag is one of the indicators which may throw light on independence of research programs or individual scientists. Usually, scientific papers are published before the citing paper or perhaps in the same year. That is, time-lag is positive, or zero, time-lag being the difference between the year of citing and the year of cited paper. The average value of time-lag within a particular citing paper or series of papers reflects how modern the paper is or how integrated it is in the evolving research front. In rapidly evolving 'hot' areas time-lag will be small and in many cases zero. If time-lag is large, say ten years, it usually indicates that the paper or series of papers belongs to a stagnating research area or is out of contact with main stream of research.

Out of 104 publications of Bhabha, 74 (71.15%) publications remain uncited. Out of 74 publications, 40 publications belonged to 'General' domain. For the purpose of calculating the time-lag only 30 (28.84%) cited publications were considered. Time-lag between publication of an article and its receiving first citation in the case of Bhabha's publications is in the range of 0 to 16 years. It was revealed that 6 (20%) publications received citations in the same year of publication, followed by 17 (56.66%) publications received citations after one year of publication, 1 (3.33%)

paper received citations after two years of publication, 1 (3.33%) paper received citations after three years of publication, 1 (3.33%) paper received citations after four years of publication, 2 (6.66%) publications received citations after nine years of publication, 1 (3.33%) paper received citations after sixteen years of publication. It was found that 86.66 percent of H. J. Bhabha's publications have received their first citations within four years of their publication indicates that his publications were

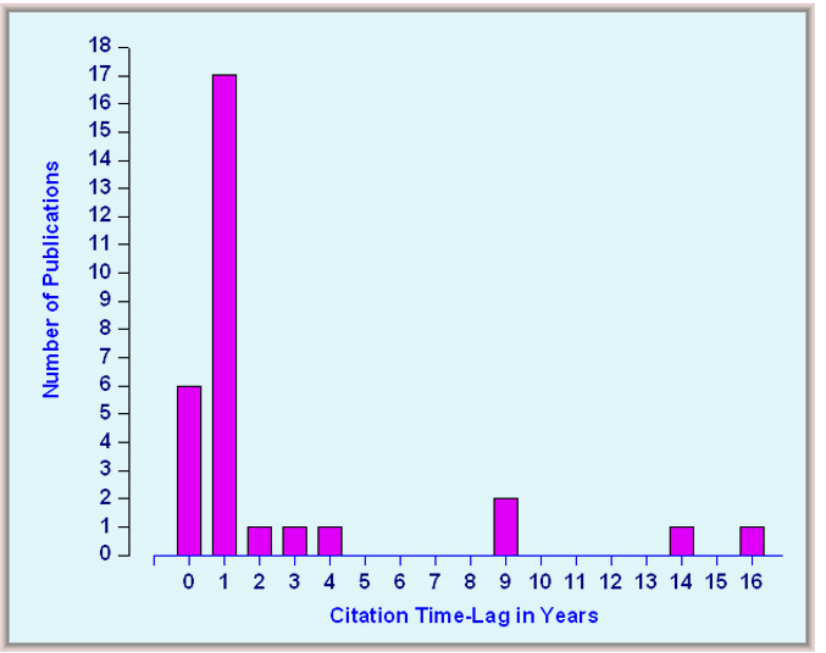


Figure 3: Citation Time-lag for H. J. Bhabha's Cited Publications

noticed instantly and had immediate direct impact among the fellow researchers working all over the world in this field. This also indicated that the publications were well integrated in the evolving research front. Only four (13.34%) publications received citations after nine years which is very negligible. In this case the contents of some of the

publications may be well ahead of time or published in the channels which are not well known and hence did not attract immediate citations. Figure-3 gives number of publications and the citation time-lag. The speed at which the publication is disseminated to the scientific community also one of the important factors that affects the publication getting noticed for the first time. During Bhabha's time, the communication process was very slow and not very well developed especially in developing countries like India.

Domain-wise Distribution of Publications and Citations

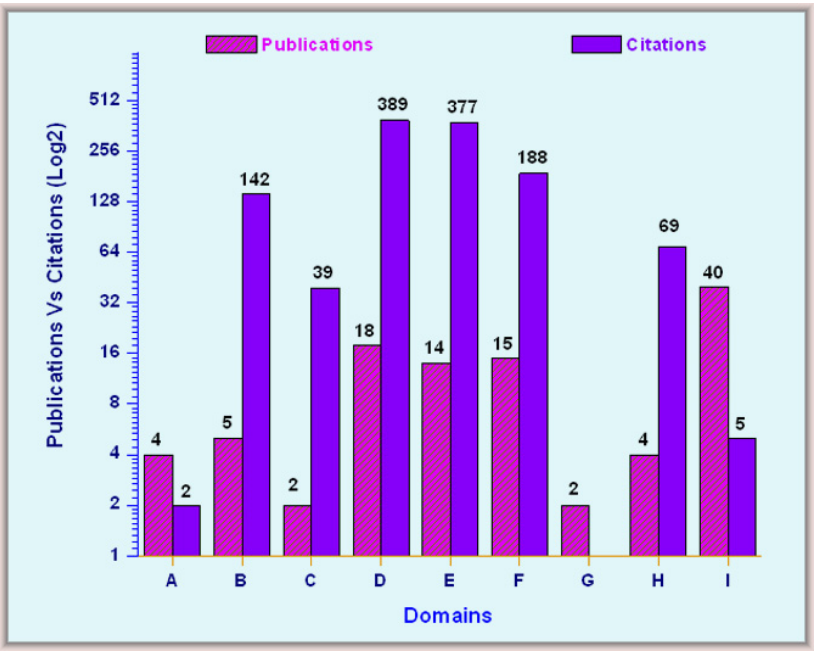
H. J. Bhabha has contributed significantly to nine main domains: Interaction of Radiation with Matter (4), Quantum Electrodynamics (5), Mathematical Physics (2), Cosmic Ray Physics (18), Elementary Particle Physics (14), Field Theory (15), General Physics (2), Nuclear Physics (4) and General (40). Domain 'Cosmic Ray Physics' has received 389 (32.12%) citations followed by 'Elementary Particle Physics' with 377 (31.13%) citations, 'Field Theory' with 188 (15.52%) citations, 'Quantum Electrodynamics' with 142 (11.73%) citations, 'Nuclear Physics' with 69 (5.70%) citations and 'Mathematical Physics 39 (3.22%) citations. There were no citations to publications in 'General Physics' domain during the period. The citation rate depends on variety of factors such as the number of people working, number of publications published, type of publications, the area of research (highly specialized or broad) etc. Table-2 gives domain-wise and year-wise publications and Figure-4 gives domain-wise publications and citations.

Communication pattern tend to be quite different in different fields. Some fields have many practitioners, some have a few. In some areas 'invisible

Table 2: Domain-wise Publications of H. J. Bhabha

Year	Domains											Productivity	Age of
	A	B	C	D	E	F	G	H	I	TP	CP	age	Bhabha
1933	1									1	1	1	24
1934	1	1								2	3	2	25
1935		2								2	5	3	26
1936	1	1	1							3	8	4	27
1937				2	1					3	11	5	28
1938				1				2		3	14	6	29
1939				1	3	1				5	19	7	30
1940					1	2				3	22	8	31
1941	1				3	2				6	28	9	32
1942		1		2						3	31	10	33
1943				1	1					2	33	11	34
1944				1	1				1	3	36	12	35
1945				2	1	2			1	6	42	13	36
1946			1	1	1	2				5	47	14	37
1947						1				1	48	15	38
1948				1	1					2	50	16	39
1949					1	1			1	3	53	17	40
1950				3				2		5	58	18	41
1951						2	1			3	61	19	42
1952						1				1	62	20	43
1953						1				1	63	21	44
1954				3			1		1	5	68	22	45
1955									3	3	71	23	46
1956									2	2	73	24	47
1957									3	3	76	25	48
1958									4	4	80	26	49
1959									2	2	82	27	50
1961									3	3	85	28	51
1962									2	2	87	29	52
1963									5	5	92	30	53
1964									6	6	98	31	54
1965									3	3	101	32	55
1966									2	2	103	33	56
1967									1	1	104	34	57
Total	4	5	2	18	14	15	2	4	40	104	-	-	-
%	3.8	4.8	1.9	17.3	13.5	14.4	1.9	3.8	38.5	100	-	-	-

(A=Interaction of radiation with matter; B=Quantum electrodynamics; C=Mathematical physics; D=Cosmic ray physics; E=Elementary particle physics; F=Field theory; G=General physics; H=Nuclear physics; I=General; TP= Total Publications; CP =Cumulative Publications)



(A=Interaction of radiation with matter; B=Quantum electrodynamics; C=Mathematical physics; D=Cosmic ray physics; E=Elementary particle physics; F=Field theory; G=General physics; H=Nuclear physics; I=General)

Figure-4: Domain-wise Publications and Citations

colleges' are very well developed and active, whereas in other areas they are not so active. Some fields are characterized by careful and substantial publications, others have a hectic assortment of feuilleton type articles. In some fields the ratio of activity to productivity, and productivity to progress is rather large, while in others small. Direct comparison of two faculty members at a university, one working in a small and careful field and other in a large and hectic one, by simply counting up their publications or citations is clearly unfair, and even grossly so. Similarly different countries might have substantially different mixes of various scientific areas and hence their publications

or citation ratings are really incomparable. Finally at different times scientists work on different types of problems which possibly have different publications and citation pattern (Moravcsik, 1973).

Citations Vs Authorship Pattern

The main features of Bhabha's publications are that he is single author in 79 (75.96%) publications and he is the first author in all his publications except one paper by Taylor et al., 1950. The number of citations received in relation to authorship pattern is given in Table-3. Single authored publications (79) have received 863

Table 3: Authorship Pattern and Citations to H. J. Bhabha's Publications

Authorship Type	Number of Publications	Number of Citations	Number of Citations per Publication	% of Citations
Single authored	79	863	10.92	71.26
Two-authored	20	341	17.05	28.16
Three-authored	1	0	0.00	0.00
Four-authored	3	7	2.33	0.58
Six-authored	1	0	0.00	0.00
Total	104	1211	11.64	100.00

(71.26%) citations and two authored publications (20) have received 341 (28.16%) citations.

Collaborators of H. J. Bhabha

H. J. Bhabha had 22 co-authors in 25 of his 104 publications. Table-4 displays the authors who co-authored publications with H. J. Bhabha in different domains along with citations. Figure- 5 gives details of researchers and their publications in collaboration with H. J. Bhabha in chronological

Table 4: Domain-wise Chronological Co-authorship Profile of H. J. Bhabha During 1933-1967

Co-authors	Domains									TP	No. of FPY-LPY	Citations/ Citations	paper
	A	B	C	D	E	F	G	H	I				
Chakrabarty, S.K				3						3	1942-1946	74	24.67
Chandrashekhar Aiya, S.V				3						3	1945-1946	7	2.33
Dayal, M.							3			3	1959-1964	0	0.00
Hoteko, H. E.				3						3	1945-1946	7	2.33
Saxena, R. C.				3						3	1945-1946	7	2.33
Daniel, R. R					1			1		2	1948-1950	1	0.50
Harish-Chandra					1	1				2	1944-1946	42	21.00
Heitler, W.	1			1						2	1936-1937	142	71.00
Prasad, N. B.									2	2	1958-1958	0	0.00
Basu, D	1									1	1942-1942	0	0.00
Carmichael, H.					1					1	1939-1939	0	0.00
Chou, C. N.					1					1	1939-1939	0	0.00
Corben, H. C						1				1	1941-1941	70	70.00
Heeramaneck, J. R.								1		1	1950-1950	0	0.00
Hulme, H. R.		1								1	1934-1934	12	12.00
Lewis, W. B.									1	1	1958-1958	0	0.00
Lonsdale, Kathleen									1	1	1967-1967	0	0.00
Madhava Rao, B. S.					1					1	1941-1941	0	0.00
Ramakrishnan, A.				1						1	1950-1950	0	0.00
Shrikantia, G. S.								1		1	1950-1950	0	0.00
Swami, M. S.								1		1	1950-1950	0	0.00
Taylor, H. J.								1		1	1950-1950	0	0.00

(A=Interaction of radiation with matter; B=Quantum electrodynamics; C=Mathematical physics; D=Cosmic ray physics; E=Elementary particle physics; F=Field theory; G=General physics; H=Nuclear physics; I=General; TP=Total Publications; FPY=First Publication Year; LPY=Last Publication Year)

order of their association (starting with first publication year). The most productive researchers with H. J. Bhabha were: S. K. Chakrabarty (1942-1946) with 3 publications which have received 74 citations, S. V. Chandrashekhar Aiya (1945-1946) with 3 publications which have received 7 citations, M. Dayal (1959-1964) with 3 publications which have not received any citations, H. E. Hoteko (1945-1946) with 3 publications which have received 7 citations, R. C. Saxena (1945-1946) with 3 publications which have received 7 citations, R. R. Daniel (1948-1950) with 2 publications which have received only one citation, Harish-Chandra (1944-1946) with 2 publications which have received 42 citations, and W. Heitler (1936-1937) with 2 publications which have received 142 citations.

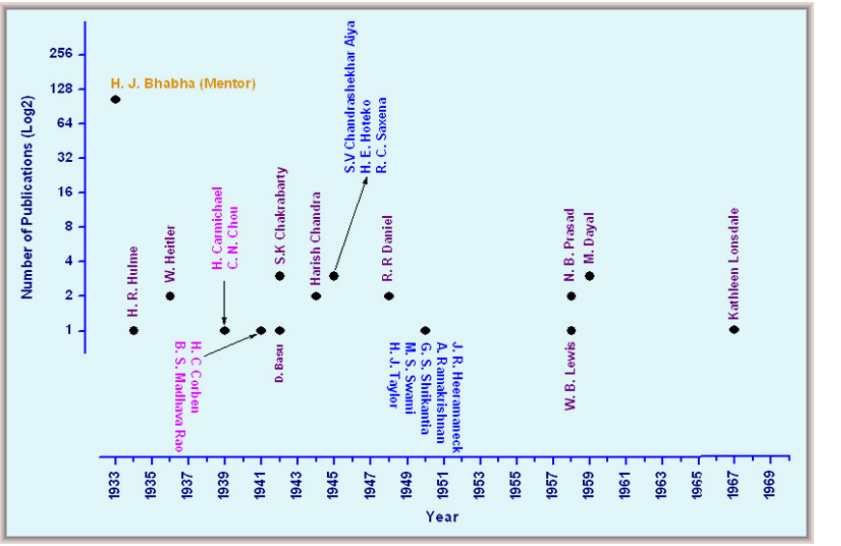


Figure 5: Co-authorship Profile of H. J. Bhabha During 1933-1967

Core Authors Citing H. J. Bhabha's Publications

All the authors appeared in the citing publications were counted. In all, there were 1567 authors citing H. J. Bhabha's publications in their publications. Citing authors with publications ≥ are listed in Table- 5. This indicates how well populated and highly integrated the research carried out by H. J. Bhabha was with the mainstream of research. The core citing authors of Bhabha's publications were: P. Havas with 26 publications followed by M. M. Nieto with 18 publications, P. M. Matthews with 17 publications, H. Messel with 16 publications, R. A. Krajcic with 15 publications, H. C. Corben with 13 publications, A. Z. Capri, M. Seetharaman, and E. C. G. Sudarshan with 11 publications each and D. Villarroel with 10 publications.

Table 5: Prominent Authors Citing H. J. Bhabha's Publications ≥4 Times

Citing Authors	Number of Publications	Rank	Citing Authors	Number of Publications	Rank
Havas, P	26	1	Salesi, G	6	12
Nieto, MM	18	2	Solodkov, A	6	12
Mathews, PM	17	3	Swann, WFG	6	12
Messel, H	16	4	Amaldi, E	5	13
Krajcik, RA	15	5	Barut, AO	5	13
Corben, HC	13	6	Brulin, O	5	13
Capri, AZ	11	7	Castagnoli, C	5	13
Seetharaman, M	11	7	Cox, W	5	13
Villarroel, D	10	8	Fujiwara, I	5	13
Ginzburg, VL	9	9	Higashi, S	5	13
Lecouteur, KJ	9	9	Hill, EL	5	13
Green, HS	8	10	Hjalmars, S	5	13
Prabhakaran, J	8	10	Hurley, WJ	5	13
Sudarshan, ECG	8	10	Johnson, TH	5	13
Vanweert, CG	8	10	Kitamura, T	5	13
Bracken, AJ	7	11	Moshinsky, M	5	13
Clay, J	7	11	Mukunda, N	5	13
Janossy, L	7	11	Nikitin, AG	5	13
Majumdar, RC	7	11	Rowe, EGP	5	13
Nordheim, LW	7	11	Santhana, TS	5	13
Rossi, B	7	11	Schein, M	5	13
Scott, WT	7	11	Shanmugadhasan, S	5	13
Takahashi, Y	7	11	Shibata, H	5	13
Umezawa, H	7	11	Shirokov, IM	5	13
Akhiezer, AI	6	12	Sinha, MS	5	13
Belenky, S	6	12	Smirnov, YF	5	13
Belinfante, FJ	6	12	Takahashi, T	5	13
Gupta, S	6	12	Tekumall, AR	5	13
Harish Chandra	6	12	Tsuneto, T	5	13
Hazen, WE	6	12	Westpfah, K	5	13
Jain, PL	6	12	Amar, V	4	14
Kokoulin, RP	6	12	Barnothy, J	4	14
Ozaki, S	6	12	Brown, LM	4	14
Pauli, W	6	12	Case, KM	4	14
Petrukhin, AA	6	12	Cecchini, R	4	14

Citing Authors	Number of Publications	Rank	Citing Authors	Number of Publications	Rank
Chakrabarty, SK	4	14	Monaldi, D	4	14
Chartres, BA	4	14	Montgomery, CG	4	14
Dozzio, U	4	14	Montgomery, DD	4	14
Eyges, L	4	14	Nagpal, AK	4	14
Feshbach, H	4	14	Nakabayasi, K	4	14
Grupen, C	4	14	Pomerantz, MA	4	14
Gyuk, I	4	14	Potts, RB	4	14
Heitler, W	4	14	Ramakrishnan, A	4	14
Hepner, WA	4	14	Riemann, T	4	14
Kirina, TM	4	14	Salvat, F	4	14
Koutroulos, CG	4	14	Schultz, PJ	4	14
Labonte, G	4	14	Shamaly, A	4	14
Lennard, WN	4	14	Sharma, A	4	14
Lynn, KG	4	14	Tamm, I	4	14
Massoumi, GR	4	14	Wessel, W	4	14

Nobel Laureates Citing Publications of H. J. Bhabha

H. J. Bhabha's publications have been cited by noted Nobel laureates like V. L. Ginzberg (9), Wolfgang Pauli (6), H. A. Bethe (3), M. Born (3), W. Bothe (3), E. P. Wigner (3), H. Yukawa (2), P. M. S. Blackett (1) and C. N. Yang (1). This is one of the indicators of the originality of his ideas and high quality of publications.

Highly Cited Publications of H. J. Bhabha

Five highly cited Publications of H. J. Bhabha could be identified as those publications which have received more than 100 citations each. Considering the period (1936-1949) during which these publications were published, had direct influence on the on-going research based on Bhabha's theories, are quite visible. The highly cited publications are very different from 'ordinary' publications. The citation curves of highly cited publications tend to follow a typical pattern of rise and fall. Highly cited publications get citations from a large number of journals belonging to close and remote

fields. Generally, citations to highly cited publications peak in the second, third, or fourth year after publication, but some publications continue to get citations for many years. A few publications can exhibit delayed recognition. The pattern can vary greatly depending on the type of publication, the field, and the nature of findings reported etc. Kademani and Kalyane have carried out a study on outstandingly cited and most significant publications of R. Chidambaram and identified highly cited publications of Vikram Sarabhai (Kademani and Kalyane, 1996 and 2000). Cardona said "In our field of physics a paper cited over the years more than 50 times has had considerable impact. If cited over 100 times it becomes an important paper" (Cardona 2003). Citation life-cycles of the five highly cited publications have been given in Figures 6a-e. Bibliographic details of all the 30 publications which have received citations are given in Table-6.

Table 6: Bibliographic Details of H. J. Bhabha's Cited Publications

Paper	Bibliographic Details of Cited Publications	TC	SC	CBO	FCY-LCY	CTL	DR	CJ	CA
P1	Bhabha, H. J. 1945. Relativistic Wave Equations for the Elementary Particles. *Rev. Mod. Phys.,* Vol. 17: pp. 200-216	189	2	187	1946-2008	1	1.06	49	199
P2	Bhabha, H. J. 1938. On the Penetrating Component of Cosmic Radiation. *Proc. Royal Soc. A,* Vol. 164: pp. 257-294	149	1	148	1938-2008	0	0.67	59	532
P3	Bhabha, H. J.; Heitler, W. 1937. The Passage of Fast Electrons and the Theory of Cosmic Showers. *Proc. Royal Soc. A,*Vol. 159: pp. 432-458	141	1	140	1937-2007	0	0.71	56	185

Paper	Bibliographic Details of Cited Publications	TC	SC	CBO	FCY-LCY	CTL	DR	CJ	CA
P4	Bhabha, H. J. 1949. On the Postulational Basis of the Theory of Elementary Particles. *Rev. Mod. Phys.,* Vol. 21, no. 3: pp. 451-462	109	2	107	1950-2004	1	1.83	39	125
P5	Bhabha, H. J. 1936. The Scattering of Positrons by Electrons with Exchange on Dirac's Theory of the Positron. *Proc. Royal Soc. A*, Vol.154: pp. 195-206	102	1	101	1938-2008	2	0.98	54	303
P6	Bhabha, H. J. and Corben, H.C.1941. General Classical Theory of Spinning Particles in a Maxwell Field. *Proc. Royal Soc. A*, Vol. 178: pp. 273-314	70	2	68	1942-2008	1	2.86	35	77
P7	Bhabha, H. J. 1939. Classical Theory of Mesons. Proc. *Royal Soc. A,* Vol. 172, no. 5: pp. 384-409	48	4	44	1940-2005	1	8.33	19	51
P8	Bhabha, H. J. and Chakrabarty, S.K 1948. Further Calculations onthe Cascade Theory. *Phys. Rev.,* Vol. 74, no. 10: pp. 1352-1363	40	0	40	1949-1998	1	0.00	11	63

Paper	Bibliographic Details of Cited Publications	TC	SC	CBO	FCY-LCY	CTL	DR	CJ	CA
P9	Bhabha, H. J. 1952. An Equation for a Particle with Two Mass States and Positive Charge Density. *Phil. Mag. Ser. VII,* Vol. 43: pp. 33-47	35	0	35	1953-2003	1	0.00	17	39
P10	Bhabha, H. J. 1938. On the Theory of Heavy Electrons and Nuclear Forces. Proc. *Royal Soc. A,* Vol. 166: pp. 501-528	34	0	34	1939-2008	1	0.00	14	38
P11	Bhabha, H. J. and Chakrabarty, S.K. 1943. The Cascade Theory with Collision Loss. *Proc. Royal Soc. A,* Vol. 181: pp. 267-303	34	2	32	1944-2002	1	5.88	15	41
P12	Bhabha, H.J. and Harish-Chandra 1946. On the Fields and Equations of Motion of Point- Particles. *Proc. Royal Soc. A,* Vol. 185: pp. 250-268	28	2	26	1945-1995	0	7.14	15	24
P13	Bhabha, H. J. 1935. On the Calculation of Pair Creation by Fast Charged Particles and the Effect of Screening. *Proc. Camb. Phil. Soc.,* Vol. 31: pp.394-406	28	0	28	1951-1987	16	0.00	17	41

Paper	Bibliographic Details of Cited Publications	TC	SC	CBO	FCY-LCY	CTL	DR	CJ	CA
P14	Bhabha, H. J. 1946. On the Expansibility of Solutions in Powers of the Interaction Constants. *Phys. Rev.,* Vol. 70, no. 9-10: pp. 759-760	27	0	27	1947-1999	1	0.00	17	31
P15	Bhabha, H. J. 1941. General Classical Theory of Spinning Particles in a Meson Field. *Proc. Royal Soc. A,* Vol. 178: pp. 314-350	26	2	24	1942-1984	1	7.69	8	25
P16	Bhabha, H. J. 1953. Production of Mesons and the Localization of Field Energy. *Proc. Royal Soc. A,* Vol. 219: pp. 293-303	26	0	26	1954-2006	1	0.00	15	45
P17	Bhabha, H. J. 1938. Nuclear Forces, Heavy Electrons and the ß-Decay. *Nature,* Vol. 141: pp. 117-118	22	1	21	1938-2008	0	4.55	17	26
P18	Bhabha, H. J. 1950. On the Stochastic Theory of Continuous Parametric Systems and its Application to electron cascades. *Proc. Royal Soc. A,* Vol. 202: pp. 301-322	18	0	18	1951-1991	1	0.00	11	16

Paper	Bibliographic Details of Cited Publications	TC	SC	CBO	FCY-LCY	CTL	DR	CJ	CA
P19	Bhabha, H. J. and Harish-Chandra 1944. On the Theory of Point Particles. Proc. *Royal Soc. A,* Vol. 183: pp. 134-141	14	3	11	1945-1995	1	21.43	9	9
P20	Bhabha, H. J. 1950. On a New Theory of Nuclear Forces. *Phys.Rev.,* Vol. 77, no. 5: pp. 665-668	13	0	13	1950-2002	0	0.00	12	21
P21	Bhabha, H. J.; Hulme, H.R. 1934. The Annihilation of Fast Positrons by Electrons in the K-Shell. *Proc. Royal Soc,* Vol. 146 A: pp.723-736	12	0	12	1938-2007	4	0.00	8	34
P22	Bhabha, H. J. 1936. The Wave Equation in Conformal Space. *Proc. Camb. Phil. Soc.,* Vol. 32: pp. 622-631	12	0	12	1945-2000	9	0.00	8	11
P23	Bhabha, H. J. 1939. The Fundamental Length Introduced by the Theory of the Mesotron (Meson). *Nature,* Vol. 143: pp. 276-277	8	0	8	1939-1989	0	0.00	6	8
P24	Bhabha, H. J. 1941. Protons of Double Charge and the Scattering of Mesons. *Phys. Rev.,* Vol. 59: pp. 100-101	8	0	8	1942-2006	1	0.00	4	10

Paper	Bibliographic Details of Cited Publications	TC	SC	CBO	FCY-LCY	CTL	DR	CJ	CA
P25	Bhabha, H. J., Chandrashekhar Aiya, S.V., Hoteko, H.E. and Saxena, R.C 1945. Meson Intensity in the Substratosphere. *Phys. Rev.,* Vol. 68, no. 7-8: pp. 147-152	7	0	7	1946-1949	1	0.00	2	9
P26	Bhabha, H. J. 1966. Science and the Problems of Development. *Science,* Vol.151, pp. 541-548. Lecture delivered by invitation of the International Council of Scientific Unions on January 7, 1966	5	0	5	1980-2002	14	0.00	3	6
P27	Bhabha, H. J. 1940. Classical Theory of Point Dipoles. *Nature,* Vol. 145: pp. 819-820	3	1	2	1941-2006	1	33.33	3	3
P28	Bhabha, H. J. and Daniel, R.R. 1948. Meson Scattering with Nuclear Excitation. *Nature,* Vol. 161: pp. 883-885	1	0	1	1949-1949	1	0.00	1	1
P29	Bhabha, H. J. 1934. Passage of Very Fast Protons Through Matter. *Nature,* Vol. 134:pp. 934-934	1	0	1	1937-1937	3	0.00	1	3

Paper	Bibliographic Details of Cited Publications	TC	SC	CBO	FCY-LCY	CTL	DR	CJ	CA
P30	Bhabha, H. J.; Heitler, W. 1936. Passage of Fast Electrons Through Matter. *Nature,* Vol. 138: p. 401-401	1	0	1	1945-1945	9	0.00	1	1
Total		1211	24	1187	-	-	1.98	526	1977

(TC= Total Citations, SC = Self-citations, CBO = Citations by others, FCY = First Citation Year, LCY = Last Citation Year, CTL = Citation Time-lag, DR = Diachronous Rate, CJ = Number of Citing Journals, CA = Number of Citing Authors)

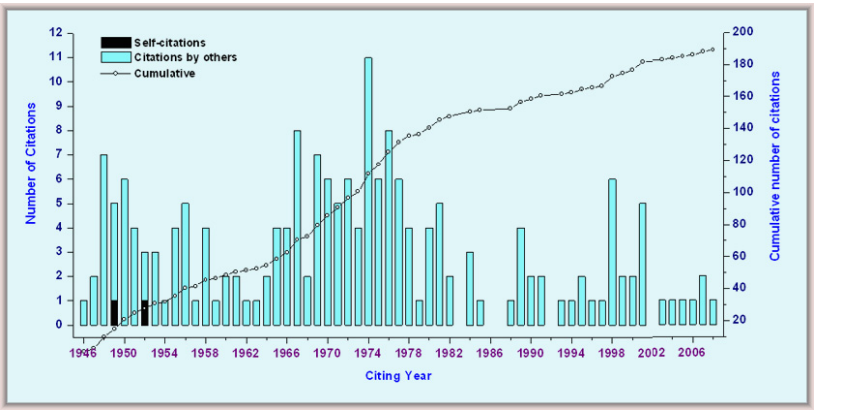


Figure 6a: Citation Life-cycle of Paper P1: Bhabha, H. J. 1945. Relativistic Wave Equations for the Elementary Particles. *Rev. Mod. Phys*., Vol. 17: pp. 200-216.

The paper P1 (Figure 6a) has received 189 citations during 1946-2008, out of which 2 were self-citations. This paper started receiving citations after one year of its publication and continues to receive citations till the period under this study. The average citations per year was 3. The highest number of citations 11 were received in 1974. There were 49 journals and 199 authors citing this paper. Diachronous self-citation rate was 1.06.

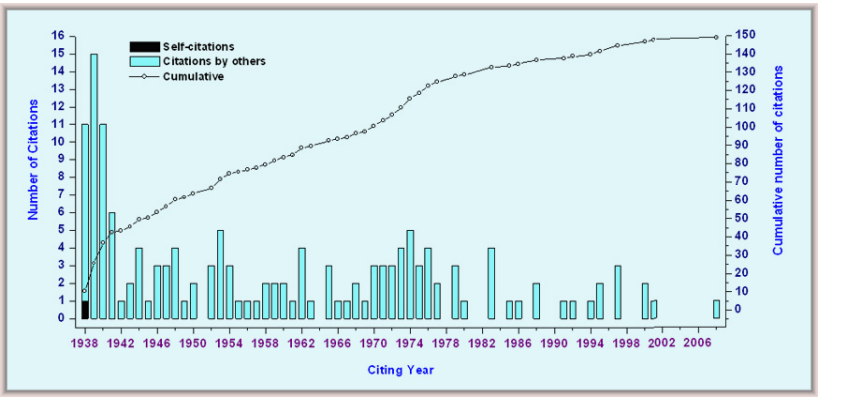


Figure 6b: Citation Life-cycle of Paper P2: Bhabha, H. J. 1938.
On the Penetrating Component of Cosmic Radiation.
Proc. Royal Soc. A, Vol. 164: pp. 257-294.

In this paper Bhabha made systematic use of group-theoretic notions, anticipating the trend towards algebraic notions in modern particle physics. His construction of an equation for a particle with two-mass states (now called Bhabha equation) is an indication of his extraordinary brilliance and great insight.

The paper P2 (Figure 6b) has received 149 citations during 1938-2008, out of which 1 was self-citation. This paper started receiving citations in the same year of its publication and continues to receive citations till the period under this study. The average citations per year was 2.10. The highest citations 15 were received in 1939. There were 59 journals and 532 authors citing this paper. Diachronous self-citation rate was 0.67.

In this classic paper experimental cosmic ray data was analysed to find a natural explanation if the secondary cosmic radiation in the atmosphere consisted of charged particles of mass intermediate between electron and proton, setting the mass around 100 electron masses. This was an original deduction, also challenging some theorists at that time who suggested that at higher energies, there occurred a breakdown of the quantum mechanical

theory. Dr. Bhabha's prediction was soon corroborated by the discovery of Neddermeyer and Anderson, and Street and Stevenson who found particles of mass ~ 200 electron masses in their cloud chamber experiments. These particles were then given the name 'meson'.

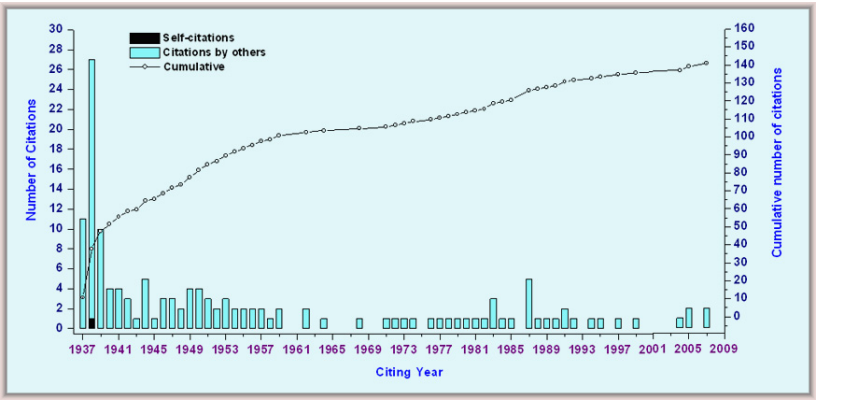


Figure 6c: Citation Life-cycle of Paper P3: Bhabha, H. J.; Heitler, W. 1937. The Passage of Fast Electrons and the Theory of Cosmic Showers. Proc. Royal Soc. A, Vol. 159: pp. 432-458.

The paper P3 (Figure 6c) has received 141 citations during 1937-2007, out of which 1 was self-citation. This paper started receiving citations in the same year of its publication and continues to receive citations till 2007. The average citations per year was 1.99. The highest citations 26 were received in 1938. There were 56 journals and 185 authors citing this paper. Diachronous self-citation rate was 0.71.

In this paper Bhabha and Heitler introduced a formal theoretical structure to the concept of cosmic air shower for the first time. They analytically estimated the physical quantities such as average number of electrons and positrons in an electromagnetic cascade, the fluctuation developed in a cascade and the angular spread of the cascade. It satisfactorily explained the results of observations by Rossi and Regener.

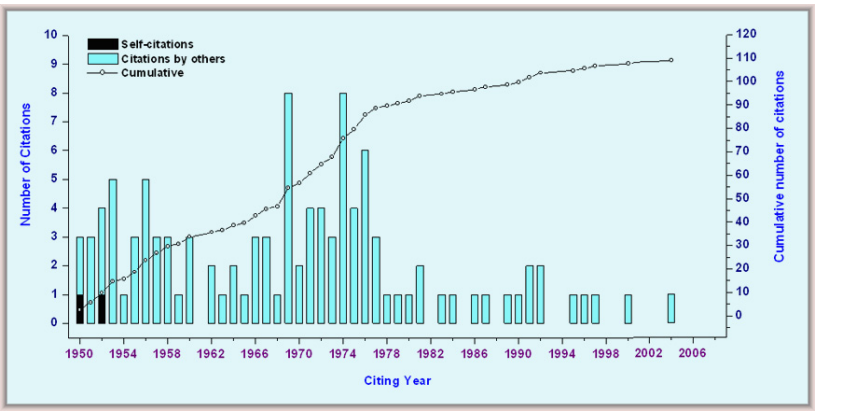


Figure 6d: Citation Life-cycle of Paper P4: Bhabha, H. J. 1949. On the Postulational Basis of the Theory of Elementary Particles. *Rev. Mod. Phys*., Vol. 21, no. 3: pp. 451-462.

The paper P4 (Figure 6d) has received 109 citations during 1950-2004, out of which 2 were self-citations. This paper started receiving citations after one year of its publication and continues to receive citations till 2004. The average citations per year was 1.98. The highest citations 8 were received in 1969 and also in 1974. There were 39 journals and 125 authors citing this paper. Diachronous self-citation rate was 1.83.

In this paper Bhabha formulated a set of postulates which lead to the relativistic wave equations of present quantum mechanics. The mathematical difference between the usual non-linear interaction terms and terms which introduce essential non-linearities in the equations is discussed. It is proved that every particle must possess an anticiparticle unless at least one of the basic postulates is discarded. The connection between the rest mass of the particle, the minimal equation of the α- matrices, and the general commutation relations of the α-matrices is derived and discussed. It is proved that for a particle of spin ½ there is only one possible wave equation, while for a particle of spin 1 there are others besides the usual scalar and vector equations.

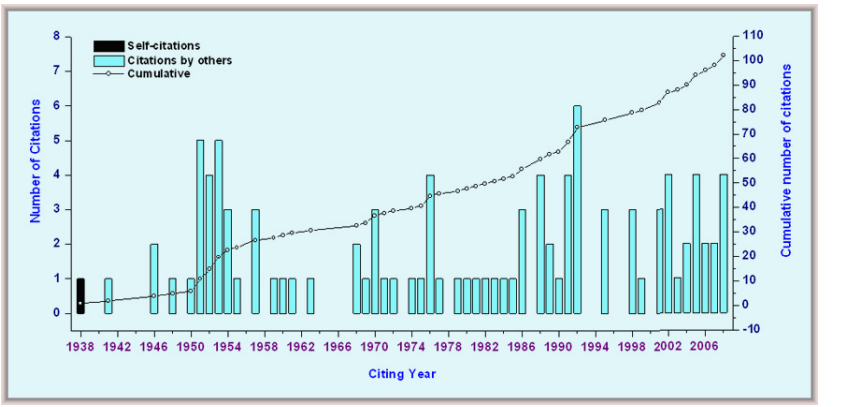


Figure 6e: Citation Life-cycle of Paper P5: Bhabha, H. J. 1936. The Scattering of Positrons by Electrons with Exchange on Dirac's Theory of the Positron. *Proc. Royal Soc. A*, Vol.154: pp. 195-206.

The paper P5 (Figure 6e) has received 102 citations during 1938-2008, out of which 1 was self-citation. This paper started receiving citations after two years of its publication and continues to receive citations till 2008. The average citations per year was 1.44. The highest citations 6 were received in 1992. There were 54 journals and 303 authors citing this paper. Diachronous self-citation rate was 0.98.

In this paper, Bhabha calculated the cross-section for electron-positron scattering which later became an eponym as 'Bhabha scattering'. There are two leading-order Feyman diagrams contributing to this interaction-an annihilation process and a scattering process. Bhabha scattering process is used to measure the luminosity in electron-positron collider beam experiments. Bhabha was the first person to discover this phenomenon. Virendra Singh (1985) considered this discovery as Bhabha's crowning achievement. This theory still being used by many scientists across the world, shows the relevance of his discovery even after 73 years of his work (Kademani, Surwase and Vijai Kumar, 2009).

Preference of Channels of Communication

It is very interesting to know what is published where and what kind of communication channel is chosen for publication in order to gain visibility. A highly qualitative paper published in an internationally well-known journal attracts the attention of the scientists instantly and receive many citations whereas an important paper published in an unknown journal may remain dormant and uncited for years.

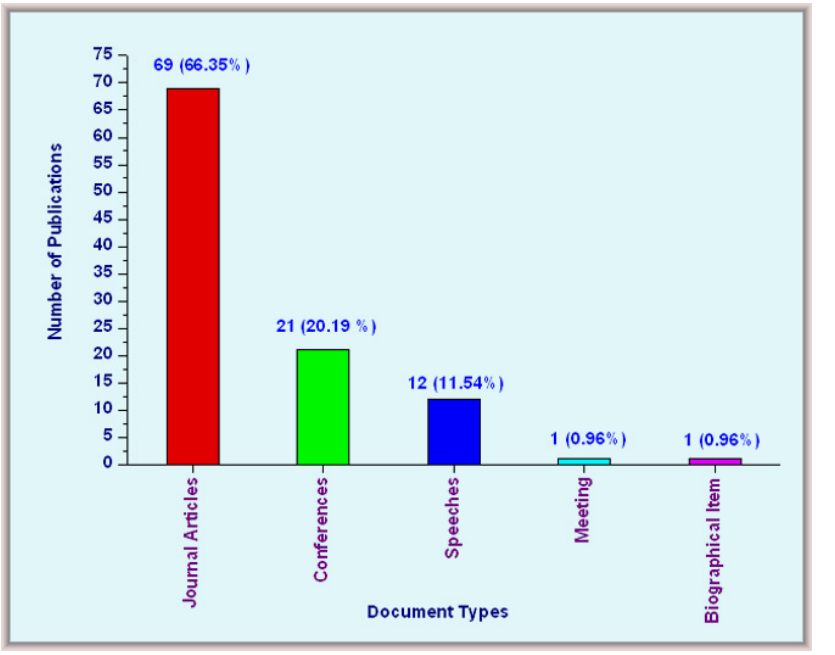


Figure 7: Distribution of Publications of
H. J. Bhabha in Terms of Types of Documents

Out of 104 publications, 69 (66.35%) were Journal Articles followed by 21 (20.19%) Conference papers, 12 (11.54%) Speeches, 1 (0.96%) Meeting and 1 (0.96%) Biographical item. Figure-7 gives H. J. Bhabha's preferences of channels of communication for publishing his publications.

Types of Citing Documents and Extent of Citations

The types of documents citing H. J. Bhabha's publications is given in Table-7. Among the citations received to H. J. Bhabha's publications, 1045 (86.29%) were from Journal articles, followed by 70 (5.78%) from Reviews, 44 (3.63%) from Letters, 19 (1.57%) from Conference Papers, 16 (1.32%) from Meeting Abstracts and 15 (1.24%) from Notes.

Table 7: Types of Documents Citing H. J. Bhabha's Publications

Citing documents	Number of citations	% of citations
Journal Articles	1045	86.29
Reviews	70	5.78
Letters	44	3.63
Conference Papers	19	1.57
Meeting Abstracts	16	1.32
Notes	15	1.24
Editorial Materials	2	0.17
Total	1211	100.00

Language-wise Distribution of Citing Publications

English has topped the list with 1167 (96.37%) citations, followed by German with 18 (1.49%) citations, Russian with 17 (1.40%) citations and French with 9 (0.74%). English is the most predominantly used language in the citing publications.

Subject-wise Distribution of Citations

Subject-wise distribution of citations is provided in Table-8. The impact of H. J. Bhabha's research is evident from the application of his research in the interdisciplinary domains of Multidisciplinary Physics (711), Particles and

Fields Physics (146), Multidisciplinary Sciences (125), Mathematical Physics (95), Instruments and Instrumentation (30), Nuclear Physics (23), Optics (15) and Nuclear Medicine and Medical Imaging Radiology (10).

Table 8: Subject-wise Distribution of Citations

Citing Subjects	Number of Citations	% of Citations	Cumulative %
Multidisciplinary Physics	711	58.71	58.71
Particles & Fields Physics	146	12.06	70.77
Multidisciplinary Sciences	125	10.32	81.09
Mathematical Physics	95	7.84	88.93
Instruments & Instrumentation	30	2.48	91.41
Nuclear Physics	23	1.90	93.31
Optics	15	1.24	94.55
Nuclear Medicine & Medical Imaging Radiology	10	0.83	95.38
Multidisciplinary Materials Science	8	0.66	96.04
Condensed Matter Physics	7	0.58	96.61
Applied Physics	6	0.50	97.11
Statistics & Probability	6	0.50	97.61
Geochemistry & Geophysics	4	0.33	97.94
History & Philosophy Of Science	4	0.33	98.27
Astronomy & Astrophysics	3	0.25	98.51
Interdisciplinary Applications Mathematics	3	0.25	98.76
Atomic, Molecular & Chemical Physics	3	0.25	99.01
Electrical & Electronic Engineering	2	0.17	99.17
Mathematics	2	0.17	99.34
Medicine, General & Internal	2	0.17	99.50
Nuclear Science & Technology	2	0.17	99.67
Multidisciplinary Chemistry	1	0.08	99.75
Mechanical Engineering	1	0.08	99.83
Applied, Mathematics	1	0.08	99.92
Microscopy	1	0.08	100.00
Total	1211	100.00	-

Journals Preferred by H. J. Bhabha for Publication and Citations

H. J. Bhabha's publications were published in 69 journals. Journal-wise scattering of Bhabha's publications in various journals is provided in Table 9

Table 9: Journals Preferred by H. J. Bhabha for Publication and Citations in These Journals

Journal Title	Number of Publications	Number of Citations	Average Citations	FPY-LPY	TY
Proceedings of the Royal Society A	12	642	53.50	1935-1953	19
Reviews of Modern Physics	2	298	149.00	1945-1949	5
Physical Review	6	95	15.83	1941-1950	10
Proceedings of the Indian Academy of Sciences A	15	48	3.20	1939-1951	13
Proceedings of the Cambridge Philosophical Society	2	40	20.00	1935-1936	2
Nature	9	36	4.00	1934-1957	24
Philosophical Magazine Series VII	1	35	35.00	1952-1952	1
Proceedings of the Royal Society	1	12	12.00	1934-1934	1
Science	1	5	5.00	1966-1966	1
Nuclear India	4	-	0.00	1963-1964	2
Current Science	2	-	0.00	1945-1945	1
Proceedings of the Indian Science Congress	2	-	0.00	1941-1941	1
Proceedings of the National Institutions of Science, India	2	-	0.00	1944-1946	3
Advancement of Science	1	-	0.00	1957-1957	1
Asian Atomic Newsletter	1	-	0.00	1964-1964	1
Calcutta-Annual number	1	-	0.00	1959-1959	1
Disarmament and Arms Control.	1	-	0.00	1963-1963	1
International Science & Technology	1	-	0.00	1939-1939	1
Journal of University of Bombay	1	-	0.00	1939-1939	1
Physical Society of Cambridge	1	-	0.00	1947-1947	1
Proceedings of the National Academy of Sciences A	1	-	0.00	1943-1951	9
Reports on Progress in Physics	1	-	0.00	1946-1946	1
Science & Culture	1	-	0.00	1942-1942	1
Zeitschrift füer Physik	1	-	0.00	1933-1933	1
Total	69	1211	17.55	-	-

He has published 12 publications in Proceedings of the Royal Society-A and these publications have received 642 citations, 2 publications in Reviews of Modern Physics have received 298 citations, 6 publications in Physical Review have received 95 citations, 15 publications in Proceedings of the Indian Academy of Sciences-A have received 48 citations, 2 publications in Proceedings of the Cambridge Philosophical Society have received 40 citations and 9 publications in Nature have received 36 citations.

Journals Citing H. J. Bhabha's Publications

There were 165 journals citing H. J. Bhabha's publications. The leading citing journals were: *Physical Review* with 262 citations, *Physical Review-D* with 74 citations, *Nuovo Cimento* with 52 citations, *Progress of Theoretical Physics* with 49 citations, *Journal of Mathematical Physics* with 43 citations, Proceedings of the *Royal Society of London-A* with 39 citations, and *Journal of Physics-A* with 35 citations. Journal-wise scattering of citations is given in Table-10.

Table 10 : Journals Citing H. J. Bhabha's Publications

Journal Title	IF 2007	Country	TC	%TC	%CTC
Physical Review	-	USA	262	21.64	21.64
Physical Review-D	4.896	USA	74	6.11	27.75
Nuovo Cimento	-	ITALY	52	4.29	32.04
Progress of Theoretical Physics	1.712	JAPAN	49	4.05	36.09
Journal of Mathematical Physics	1.018	USA	43	3.55	39.64
Proceedings of the Royal Society of London-A	1.338	ENGLAND	39	3.22	42.86

Journal Title	IF 2007	Country	TC	%TC	%CTC
Journal of Physics-A	1.577	ENGLAND	35	2.89	45.75
Reviews of Modern Physics	33.508	USA	24	1.98	47.73
Nuovo Cimento della Societa Italiana di Fisica-A	-	ITALY	19	1.57	49.30
Zeitschrift fur Naturforschung-A	0.904	GERMANY	17	1.40	50.70
Nuovo Cimento della Societa Italiana di Fisica-B	0.351	ITALY	16	1.32	52.02
Physica	-	NETHERLANDS	16	1.32	53.34
Proceedings of the Cambridge Philosophical Society	0.536	USA	16	1.32	54.67
Nuclear Physics -B	5.199	NETHERLANDS	15	1.24	55.90
Proceedings of the Physical Society of London -A	-	ENGLAND	15	1.24	57.14
Soviet Physics JETP	-	USA	15	1.24	58.38
Annals of Physics	3.019	USA	14	1.16	59.54
Physical Review- A	3.047	USA	14	1.16	60.69
Nuclear Physics	-	NETHERLANDS	13	1.07	61.77
Nuclear Instruments & Methods in Physics Research -A	1.185	NETHERLANDS	12	0.99	62.76
Annalen der Physik	1.431	GERMANY	11	0.91	63.67
Comptes Rendus de L Academie des Sciences del URSS	-	RUSSIA	11	0.91	64.57
Journal de Physique et le Radium	-	FRANCE	11	0.91	65.48
Progress of Theoretical Physics-Supplement	1.712	JAPAN	11	0.91	66.39
Reports on Progress in Physics	9.549	ENGLAND	11	0.91	67.30
American Journal of Physics	0.919	USA	10	0.83	68.13
Canadian Journal of Physics	0.756	CANADA	10	0.83	68.95
Foundations of Physics	0.854	USA	10	0.83	69.78
Physical Review Letters	7.072	USA	10	0.83	70.60
Zeitschrift füer Physik	-	USA	10	0.83	71.43
2 journals with 9 citations	-	-	18	1.49	72.91
6 journals with 8 citations	-	-	48	3.96	76.88
6 journals with 7 citations	-	-	42	3.47	80.35
3 journals with 6 citations	-	-	18	1.49	81.83
7 journals with 5 citations	-	-	35	2.89	84.72
3 journals with 4 citations	-	-	12	0.99	85.71
17 journals with 3 citations	-	-	51	4.21	89.93
31 journals with 2 citations	-	-	62	5.12	95.05
60 journals with 1 citation	-	-	60	4.95	100.00
Total	1211	100.00	-		

(IF=Impact Factor; TC=Total Citations; CTC=Cumulative Total Citations)

Distribution of Citing Journals According to Impact Factors

The dynamics and internal structure of the system of scientific communication are greatly influenced by varying quality of the primary journals in which scientific communications are published. The analysis of citations is one of the means by which policy makers, scientists and librarians seek to achieve a greater understanding of the qualitative forces that affect formal communications in science. The higher indices of "immediacy" tend to produce higher measures of "impact" and the eminence of the journals is determined mainly by the impact factor.

More than 63 percent of the citations received were from journals with impact factors ranging from 0.001 to 1.000 indicating the quality of H. J. Bhabha's publications. The distribution of citing journals as per impact factors is given in Table-11.

Table 11: Impact Factor-wise Distribution of Citations

Impact Factor (*JCR* 2007)	Number of Citations	Number of Citing Journals	% of Citations
0.001-1.000	764	106	63.088
1.001-2.000	193	21	15.937
2.001-3.000	39	13	3.220
3.001-4.000	43	10	3.551
4.001-10.000	130	11	10.735
10.001-34.000	42	4	3.468
Total	1211	165	100.000

Country-wise Distribution of Citing Journals

Table-12 gives the country-wise distribution of citing journals and number of citations. Among the top ranking journals citing H. J.

Table 12: Country-wise Distribution of Citing Journals

Journal Publishing Country	Citations	% Citations	Cumulative %
USA	597	49.30	49.30
ENGLAND	164	13.54	62.84
NETHERLANDS	116	9.58	72.42
ITALY	100	8.26	80.68
JAPAN	67	5.53	86.21
RUSSIA	47	3.88	90.09
GERMANY	39	3.22	93.31
FRANCE	22	1.82	95.13
CANADA	11	0.91	96.04
INDIA	11	0.91	96.94
SINGAPORE	11	0.91	97.85
AUSTRALIA	4	0.33	98.18
SWEDEN	4	0.33	98.51
CZECH REPUBLIC	3	0.25	98.76
AUSTRIA	2	0.17	98.93
HUNGARY	2	0.17	99.09
SOUTH KOREA	2	0.17	99.26
BYELARUS	1	0.08	99.34
DENMARK	1	0.08	99.42
MEXICO	1	0.08	99.50
PEOPLES R CHINA	1	0.08	99.59
PHILADELPHIA	1	0.08	99.67
POLAND	1	0.08	99.75
SWITZERLAND	1	0.08	99.83
UKRAINE	1	0.08	99.92
VENEZUELA	1	0.08	100.00
Total	1211	100.00	-

Bhabha's publications were from USA with 597 (49.30%) citations followed by England with 164 (13.54%) citations, The Netherlands with 116 (9.58%) citations, taly with 100 (8.26%) citations, and Japan with 67 (5.53%) citations.

Keyword Tomography

Keywords are one of the best scientometric indicators to understand and grasp instantaneously the thought content of the publications and to find out the growth of the subject field. By analyzing the keywords appeared either on the title or assigned by the indexer or the author himself will help in knowing in which direction the knowledge grows. The high frequency keywords will enable us to understand what are all the aspects on which H. J. Bhabha carried out his research and what are all the aspects for which his research publications have been cited.

Keywords Appeared in the Titles of Publications of H. J. Bhabha

The keywords appeared in the publications of H.J. Bhabha are listed in Table- 13 and 14. The high frequency keywords were: Cascade theory (4), cosmic radiation (4), Theory of Elementary particles (4), and relativistic wave equations (3).

Table 13: Keywords Appeared in the Titles of Publications of H. J. Bhabha with Frequency ≥2

Keyword	Frequency
Cascade theory	4
Cosmic radiation	4
Theory of Elementary particles	4
Relativistic wave equations	3
Collision loss	2
Electrons in the K-shell	2
General classical theory	2
Matter	2
Meson intensity	2
Passage of electrons	2
Power programme in India	2
Science and problems of development	2
Substratosphere	2

Table 14: Keywords Appeared in the Titles of Bhabha's Publications with One Frequency

Annihilation; Atomic energy; Atomic energy and Indian economy; Atomic energy and industrial development; Calculation of pair creation; Canada-India Reactor; Classical and quantum theories; Classical theory of Electrons; Classical theory of mesons; Classical theory of point dipoles; Classical theory of spinning particles; Complete stochastic treatment; Conformal space; Continuous parametric systems; Dirac's theory of positron; Economics of nuclear power; Electron cascades; Electronic and non-electronic components; Electrons and quanta; Elementary heavy particles; Elementary particles; Equations of motion of point-particles; Expansibility of solutions; Experimental test; Fast charged particles; Fast positrons; Heavy electrons; Heavy mesons; High altitude measurements; India's development strategy; Intensity of cosmic radiation; International cooperation; K. S. Krishnan; Keywords-Bhabha; Latitude effect for mesons; Localization of field energy; Mean square deviation; Meson scattering; Multiple meson production; Negative protons; Neutral mesons; New theory of nuclear forces; Nuclear disarmament; Nuclear excitation; Nuclear forces; Nuclear plates; Nuclear power in India - economic aspects; Particle with two mass states; Particles of arbitrary spin; Passage of Fast protons; Penetrating component; Positive charge density; Postulation basis; Powers of the interaction constants; Production of bursts; Production of mesons; Proton-neutron exchange interaction; Protons; Protons of double charge; Radiation reaction; Relativistic equations; Relativistic wave equations; Relativistic wave equations of spin 3/2; Role of atomic Energy- India; Role of atomic energy-Asia; Role of atomic power in India; Role of science and technology; Scattering of charged mesons; Scattering of mesons; Scattering of positrons; Scattering phenomenon; Scientific developments in India; Solid emulsion block; Spin half and Compton effect; Spin of the mesons; Spinning particles in a meson field; Spinning particles in Maxwell field; Stars and single tracks; Stochastic theory; Theory of cosmic showers; Theory of fundamental particles; Theory of particles; Theory of point particles; Underdeveloped countries; Wave equation; World energy requirements; and β-decay.

Keywords Appeared in the Citing Publications

The keywords appeared in Key Words Plus field in Web of Science of citing publications were analysed to assess the impact of H. J. Bhabha's publications. The high frequency keywords were: Fields (16), Model (15),) Quantization (8), Dirac-Equation (7), Field (7), Particles (7), Bremsstrahlung (6), Electrons (6), Mass (6), Multiple-Scattering (6), Pair Production (6), Quantum-Mechanics (6); Scattering (6). Table–15 gives a list of high frequency keywords appeared in the citing publications. Keywords with one frequency are listed in Table-16.

Table 15: Keywords Appeared in the Citing Publications with ≥2 Frequency

Keyword	Frequency	Keyword	Frequency	Keyword	Frequency
Fields	16	Radiative-Corrections	4	Maxwell Equations	2
Model	15	Rays	4	Molecules	2
Quantization	8	Slow Mesotrons	4	Monoenergetic Positrons	2
Dirac-Equation	7	Solids	4	Monte-Carlo	2
Particles	7	Zitterbewegung	4	Multifractality	2
Bremsstrahlung	6	2-Body Problems	2	Numerical-Solutions	2
Electrons	6	Air Showers	2	One-Loop Corrections	2
Mass	6	Ca-40	2	Particle	2
Multiple-Scattering	6	Calorimeter	2	Passage	2
Pair Production	6	Chamber Response	2	Photon Transport	2
Quantum-Mechanics	6	Charged-Particles	2	QCD	2
Scattering	6	Classical Electrodynamics	2	Rapidity Spectra	2
Arbitrary Spin	5	Definition	2	Relativistic Electrons	2
Backscattering	5	Diagrams	2	Relativistic Problems	2
Distributions	5	Dynamics	2	Relativistic Rotator	2
Electrodynamics	5	E(+)E(-) Collisions	2	Relativistic Wave-Equations	2
Electron	5	E+E Annihilation	2	Relativistic Zitterbewegung	2

Keyword	Frequency	Keyword	Frequency	Keyword	Frequency
Electron-Structure	5	Electromagnetic-Field	2	Representations	2
Extrinsic Curvature	5	Energy	2	Shell	2
Nuclei	5	Energy-Loss	2	Simulation	2
Radiation Reaction	5	Fast Protons	2	Skyrme Model	2
Spectra	5	Feynman Rules	2	Spinning Particles	2
Atoms	4	Formalism	2	State	2
Collisions	4	Fully Stripped Ions	2	Stopping Power	2
Complex Numbers	4	Global Optical Potentials	2	Superalgebras	2
Cross-Sections	4	Grassmann Variables	2	Supermultiplets	2
Disintegration	4	Gravity	2	Superparticle	2
Field-Theory	4	Head-On Collisions	2	Surfaces	2
General-Relativity	4	Heavy-Ion Collisions	2	Symmetry	2
Hard Component	4	High-Energy	2	Symplectic Structures	2
Mean-Free-Path	4	Integrals	2	Terms	2
Mechanics	4	Invariance	2	Thin-Films	2
Nuclear-Forces	4	Kinetics	2	Time	2
Orbital Electrons	4	Low-Energy Electrons	2	Transition	2
Poincare Group	4	Low-Energy Positrons	2	Transport	2
Positron	4	Mass-Loss	2		-

Table 16: Keywords with One Frequency Appeared in the Citing Publications

10-100 Kev Electrons; 1st-Order Dirac-Equation; 1st-Order Wave-Equations; 2-Loop; 2-Loop Qed Corrections; 2-State System; 3 Dimensions; 3-Jet Events; 5 Mev Lab; Accelerated Frames; Accelerators; Algebras; Aluminum; Amplitudes; Angle Bhabha Scattering; Angles; Annihilation; Anomalies; Antimuonium Conversion; Antisymmetric Tensor-Fields; Asymmetry; Atmosphere; Atomic-Field Bremsstrahlung; Axion Production; Batalin-Fradkin Quantization; Bonnet; Box-Diagram Contributions; Breit Interaction; Brownian-Motion; Brst Quantization;

Buildup Region; Calorimeters; Canonical Quantization; Canonical Realizations; Carlo Event Generator; Cartan Space-Time; Casimir Force; Cerenkov Radiation; Chaos; Charge; Chiral Anomalies; Chiral Perturbation-Theory; Chiral-Schwinger Model; Classical Equations; Classical Mechanics; Classical Motion; Classical-Model; Cloud-Chamber; Clusters; Compact Matrix Pseudogroups; Compatibility; Compton-Scattering; Condensed Matter; Configuration-Space; Connection; Construct; Conversion; Corpuscular Radiation; Cosmic-Ray Cascades; Cosmic-Ray Particles; Cosmological Constant Problem; Cross-Section; Curvature; Curved Space; Curved-Spacetime; Damped Harmonic-Oscillator; Decay-Rate; Decomposition; Deep-Inelastic Scattering; Deposition; Depth; Differential Cross-Sections; Differential-Equations; Differential-Equations Method; Diffusion; Dimension; Dimensional Reduction; Dimensions; Dipole; Dipole Approximation; Dirac Electron; Dirac-Like Equations; Disintegration Curve; Dissociative Ionization; Dose Calculation Tool; Dosimetry; Double Box; Duffin-Kemmer-Petiau; E(+)E(-) Annihilation; E,2e Processes; Early Universe; EGS4; Electromagnetic Calorimeter; Electron Contamination; Electron Momentum Distribution; Electronic Stopping Power; Electron-Impact Ionization; Electron-Positron Scattering; Electroproduction; Electroweak Form-Factor; Electroweak Standard Model; Elementary-Particle Physics; Energy E(+)E(-) Colliders; Energy Positron; Energy-Dependence; Epsilon-Expansion; Equivalence; Etran; Evolution; Exchange; Expectation Value; Factorial Moment Ratio; Fast Charged-Particles; Feynman Diagrams; Feynman Graph Amplitudes; Field Theory; Film; Flat Space; Flight; Fluctuations; Fock Equations; Foldy-Wouthuysen Transformations; Formula; Formulation; Fractional Spin; Fragmentation; Free-Mass Position; Front; Galactic Cosmic-Rays; Gelation; Gluon Bremsstrahlung; Gravitational-Field; Group Quantization; Guide; H2O; Hadron-Hadron Collisions; Hamiltonian Brst

Quantization; Hamiltonians; Hamilton-Jacobi Theory; Hard Photon Corrections; Harmonic Polylogarithms; Harmonic-Oscillator; High Transverse-Momentum; High-Energies; High-Energy Collisions; High-Energy Photon; Higher Derivatives; Higher-Order Equations; Highly-Charged Ions; Impact Ionization; Implantation; Incident; Inelastic-Collisions; Inorganic Materials; Intense; Interface; Intermediate; Ionization; Ionization Loss; Ionizing Particles; Iron; Irreducible Representations; Kev Electron; Klein Paradox; K-Shell; L3 Experiment; Ladder-Diagram Contributions; Lagrangian Formulation; Large-Angle; Laser Fields; Lattice; Lead; Lep; Lie Structures; Light; Liquid Argon Calorimeter; Liquid Water; Localization; Loop Corrections; Losses; Magnetic-Field; Magnetic-Moment; Many-Body Theory; Mass Shift; Mass Singularities; Massive Gauge-Theories; Massive Vector-Fields; Massless Particles; Mean Free-Path; Media; Medical Linear Accelerators; Megavoltage Photon; Mesons; Metallic Beryllium; Model Atom; Models; Modes; Momentum; Momentum-Transfer Processes; Monitor Chamber Backscatter; Monte-Carlo Simulation; Moving Mirror; Multilayer Systems; Multiple Elastic-Scattering; Multiple Source Model; Multiply Charged Ions; Muon Catalyzed Fusion; Muon Lifetime; Neutral Atoms; Neutral Particle; Neutrino; NH3; Noncommutative Geometry; Noninteracting-Blip Approximation; Normalized Cumulants; Nucleus-Nucleus Collisions; Numerical Evaluation; Nusex; Observables; Ohmic Dissipation; One Dimension; Operator; Optical-Data; Optical-Systems; Order Harmonic-Generation; Order Radiative-Corrections; Organic-Compounds; Oscillator; Oscillator-Strengths; Particle Horizons; Particle Multiplicity Distributions; Path-Integral Derivation; PBAR Collider Experiments; Penetration; Perturbation; PHI-3 Theory; Photoproduction; Point Particles; Point Sources; Polarization; Positive Excess; Positron Lines; Positron-Helium Scattering; Positrons; PP Collisions; Profiles; Pulses; Radiating Electrons;

Rapidity Dependence; Ratio; Relativistic Dynamics; Relativistic-Particles; Riemann Spaces; Root-S; Root-S=189 Gev; Scalar Integrals; Scattering Cross-Sections; Schwinger; Science; Scintillator Hadron Calorimeter; Sea-Level; Self-Duality; Semiclassical Gravity; Shattering Transition; Silicon Tungsten Calorimeter; Simulations; Single-Component; Single-Ionization; Single-Quantum Annihilation; Slab Absorbers; Slow Mesons; Soft X-Rays; Spaces; Space-Time; Spectral Geometry; Spectral Structure; Spectrometer; Spectroscopy; Spectroscopy Epes; Speed; Spin 1/2 Particle; Squeezed States; Stability; Standard Model; Standard Quantum Limit; Stochastic Fractals; Stopping-Power Formula; Strip Detectors; Strong Electroweak Sector; Stuckelberg-Kibble Model; Subleading Sudakov Logarithms; Substances; Substrate; Supergravity; Super-Kamiokande; Supersymmetric Dirac Particles; Supersymmetrization Procedure; Supersymmetry; Swift Charged-Particles; Systems; Target; Target Bremsstrahlung Calculations; Tensor; Th Collisions; Theorem; Thermal Environment; Thin Metal-Films; Threshold Behavior; Top-Quark Production; Trace Anomalies; Transformation; Transitions; Transmission; Tunneling Ionization; Turbulence; U(1) Gauge-Theory; Undergraduate Experiment; Unified Electroweak Forces; Universal Fermi Interaction; Vacuum Energy; Variable Mass; Variable-Energy Positrons; Vavilov Distribution; Velocity N-7+ Ions; Version; Virtual Corrections; Water; Wave-Equation; Wave-Function; Wavefunctions; Weinberg Model; X-Ray-Production; and Yang-Mills Theory.

CONCLUSION

Quantitative and qualitative analysis with graphic representation of the publication productivity of a scientist facilitates easy and clear perception about the work of a scientist. Bhabha's scientific work spanned over more than three decades (1933-1967) during which he published 104 publications, which could be classified into nine fields: Interaction of Radiation with Matter (4), Quantum Electrodynamics (5), Mathematical Physics (2), Cosmic Ray Physics (18), Elementary Particle Physics (14), Field Theory (15), General Physics (2), Nuclear Physics (4) and General (40). The highest number of publications (6) were published in 1941, 1945 and 1964 respectively. The average number of publications published per year was 3.05. His productivity coefficient was 0.50 which is a clear indication that his publication productivity was quite consistent throughout his scientific career. He was single author in 79 of his publications and the main author in 24 publications indicates that he always preferred to work himself and lead the team as 'mentor'. Bhabha had 22 collaborators during the period. Team of research collaborators working with a successful scientist documents the sociological aspect of history of science while generating knowledge by a leader in a domain.

Bhabha became a citable author in 1937. Bhabha received 1211 citations to his 30 publications out of 104 publications. Out of 104, 74 publications did not receive any citations. Out of 74 publications, 40 publications dealt subjects mainly of general interest. Bhabha's 86.66 percent of cited publications received their first citations within four years of their publication indicates that his publications were noticed immediately and had direct impact among the fellow researchers working all over the world. His overall citation rate was 11.64 per cited publication. The highest citations 389 were received to the domain 'Cosmic ray physics'. The highest number of citations received were 45 in 1938. His self-citations were only 24 (1.98%) and citations by others were 1187 (98.02%). The highest self citations were

six in 1946. Bhabha's mean diachronous self-citation rate was 1.98. The highest citation rate 28.4 was to the domain 'Quantum electrodynamics. His single authored publications have received the highest number 863 (71.26%) of citations. Bhabha's five publications have been cited more than 100 times each. His publications have been cited by the authors working in various diverse fields like nuclear physics, mathematical physics, instrumentation, optics, geophysics and geochemistry, condensed matter physics, applied physics, electrical and electronic engineering, mechanical engineering etc., indicating a very diverse influence and impact of Bhabha's publications. Bhabha's publications have also been cited by the Nobel laureates like V. L. Ginzberg, Wolfgang Pauli, H. A. Bethe, M. Born, W. Bothe, E. P. Wigner, H. Yukawa, P. M. S. Blackett and C. N. Yang which is an indication of his originality of ideas and high quality of publications.

Core journal titles and the keywords in the titles of the articles provide glimpses of the domains Bhabha addressed to may generate new interest among many researchers. It will be quite interesting if one attempts to study the reasons for which Bhabha's publications have been cited.

REFERENCES

1. Anderson, R. S. (1975). Building scientific institutions in India: Saha and Bhabha. Centre for Developing Area Studies: Montreal.
2. Angadi, M.; Koganuramath, M.M; Kademani, B. S.; Kalyane, V. L. and Sen, B. K. (2004). Scientometric portrait of Nobel laureate Leland Hartwell. International Workshop on Webometrics, Informetrics and Scientometrics, IIT, Roorkee (India), 2-5, March, 2004: pp. 10-30.

3. Angadi, M.; Koganuramath, M. M.; Kademani, B. S.; Jange, S. and B. D. Kumbar (2006). Nobel Laureate Anthony J Leggett : A scientometric portrait. Annals of Library and Information Studies. Vol. 53 (4): pp. 203-212.

4. Angadi, Mallikarjun; Koganuramath, M.M; Kademani, B. S. and Kumbar, B.D. and Jange, Suresh. (2007). Scientometric portrait of Alan J Heeger. Third International Conference on Webometrics, Informetrics, Scientometrics, Science and Society and Eighth Collnet Meeting, 6-9 March 2007, New Delhi: pp. 223-233.

5. Bhabha, J. Ed. (1965). Homi Bhabha as artist: Selection of his paintings, drawings and sketches, Mumbai: Marg Publications.

6. Brown, P. (1993). Has the AIDS research epidemic spread too far? New Scientist. Vol. 138 (1873): pp. 12-15.

7. Cawkell, T. and Garfield, E. (1980). Assessing Einstein's impact on today's science by citation analysis. In: Einstein: The first hundred years, ed. by M Goldsmith et al., Pergamon, Oxford: pp. 31-40.

8. Cardona, M. (2003). William Paul: a scientist, teacher, and a friend. Physics of the Solid State B. Vol. 235 (2): pp. 211-220.

9. Cockcroft, J. and Menon, M. G. K. (1967). Homi Jehangir Bhabha (1909-1966). The Royal Institution of Great Britain.

10. Cronin, B. (1984). The citation process: The role and significance of citation in scientific communication. London, Taylor Graham.

11. Deshmukh, Chintamani. (2005). Homi Jehangir Bhabha. New Delhi: National Book Trust.

12. Dieks, D. and Slooten, W. J. (1986). Historic papers in physics- The case of Hugo martin tetrode, 1895-1931. Czech. Journal of Physics B. Vol. 36: pp. 39-42.

13. Freund, P. (2007). A passion for discovery. New Jersey: World Scientific.

14. Goldstein, G. R. (1990). Michael J. Moravcsik: A Biographical Sketch. Few Body Systems. Vol. 9: pp. 41-56.

15. Gami, A. S.; Montori, V. M.; Wilczynski, N. L. and Haynes, R. B. (2004). Author self-citation in the diabetes literature. CMAJ, Vol. 17 (13): pp. 1925-1927.

16. Garfield, E. (1977). Caution urged in the use of citation analysis. Trends in Biochemical Sciences. Vol. 2 (4): pp. N84.

17. Garfield, E. (1978). Citation analysis as a tool in journal evaluation. Science, Vol. 168: pp. 471-479.

18. Garfield, E. (1979). Citation indexing: Its theory and application in science, technology and humanities. Wiley, New York.

19. Garfield, E. (1979). Is citation analysis a legitimate tool? Scientometrics. Vol.1 (4): pp. 359-375.

20. Garfield, E. (1994). The concept of citation indexing: A unique and innovative tool for navigating the research literature. Current Contents. Vol. 4: pp. 3-6.

21. Garfield, E. (1994). The relationship between citing and cited publications: A question of relatedness. Current Contents. Vol. 34 (17): pp. 3-5.

22. Ghosh, J. S. and Neufeld, M. L. (1974). Uncitedness of articles in the Journal of the American Chemical Society. Information Storage and Retrieval. Vol.10: pp. 365-369.

23. Ghosh, J. S. (1975). Uncitedness of articles in Nature: A multidisciplinary scientific journal. Information Processing & Management. Vol. 11: pp. 165-169.

24. Glanzel, W.; Thijs, B.; and Schlemmer, B. (2004). A bibliometric approach to the role of author self-citations in scientific communication. Scientometrics. Vol. 59: pp. 63-77.

25. Gupta, D.K (1978). Plate Tectonics: A study transmission of Ideas. Annals of Library Science and Documentation. Vol. 25 (1-4): pp. 86-92.

26. Gupta, D. K. and Gupta, S. A. (1983). A Citography on LePichon's Article on Sea-Floor Spreading and Continental Drift: Application of Bradford's Law. IASLIC Bulletin. Vol. 28 (2): pp. 49-58.

27. Havanur, S. (2006). Dr. H. J. Bhabha. Bangalore, Sapna Book House.

28. Kademani, B. S.; Kalyane, V. L. and Kademani, A. B. (1994). Scientometric portrait of Nobel laureate Dr. C. V. Raman. Indian Journal of Information, Library and Society. Vol. 7(3-4): pp. 215-249.

29. Kademani, B. S.; Kalyane, V. L. and Balakrishnan, M. R. (1994). Scientometric portrait of P. K. Iyengar. Library Science. Vol. 31 (4): pp. 155-176.

30. Kademani, B. S. and Kalyane, V. L. (1996a). Bibliometric indicators of publication productivity analysis of an individual scientist. JISSI: The International Journal of Scientometrics and Informetrics. Vol. 2 (4): pp. 49-58.

31. Kademani, B. S. and Kalyane, V. L. (1996b). Outstandingly cited and most significant publications of R. Chidambaram, a nuclear physicist. Malaysian Journal of Library and Information Science. Vol.1: pp. 21-36.

32. Kademani, B. S.; Kalyane, V. L. and Kademani, A. B. (1996). Scientometric Portrait of Sir K. S. Krishnan. Indian Journal of Information Library and Society. Vol. 9 (1-2): pp. 125-150.

33. Kademani, B. S.; Kalyane, V.L. and Kademani, A. B. (1996). Scientometric portrait of Nobel laureate S. Chandrasekhar. JISSI : The International Journal of Scientometrics and Informetrics. Vol. 2(2-3): pp. 119-135.

34. Kademani, B. S. and Kalyane, V. L. (1998). Scientometric portrait of R. Chidambaram, the Indian Nuclear Physicist: Based on citation analysis. Kelpro Bulletin. Vol. 2: pp. 13-29.

35. Kademani, B.S.; Kalyane, V. L. and Jange, S. (1999). Scientometric portrait of Nobel laureate Dorothy Crowfoot Hodgkin. Scientometrics. Vol. 45 (2): pp. 233-250.

36. Kademani, B. S.; Kalyane, V. L. and Vijai Kumar. (2000). Scientometric portrait of Vikram Ambalal Sarabhai: A citation analysis. SRELS Journal of Information Management. Vol. 37 (2): pp. 107-132.

37. Kademani, B. S.; Kalyane, V. L. and Vijai Kumar (2001). A. H. Zewail: Research Collaborator par excellence. Scientometrics. Vol. 53: pp. 113-121.

38. Kademani, B. S.; Kalyane, V. L. and Vijjai Kumar. (2002a). Scientometric portrait of Nobel laureate Harold W. Kroto. SRELS Journal of Information Management. Vol. 39 (4): pp. 409-434.

39. Kademani, B. S.; Kalyane, V. L. and Vijai Kumar. (2002b). Scientometric portrait of Nobel Laureate Ahmed Hassan Zewail. Malaysian Journal of Library and Information Science. Vol. 6 (2): pp. 53-70.

40. Kademani, B. S.; Kalyane, V. L.; Vijai Kumar and Lalit Mohan. (2005). Nobel laureates: Their publication productivity, collaboration and authorship status. Scientometrics. Vol. 62 (2): pp. 261-268.

41. Kademani, B. S.; Kalyane, V. L.; Vijai Kumar and Lalit Mohan. (2006). Letter to the Editor. Scientometrics. Vol. 66 (3): pp. 615-617.

42. Kademani, B. S. and Anil Sagar. (2007). Scientometric Portrait of Dr. Vijai Kumar: A Scientist par excellence. In Collected Scientific Publications of Dr Vijai Kumar, Compiled by B. S. Kademani and Anil Sagar, Scientific Information Resource Division, Bhabha Atomic Research Centre, Mumbai: pp. xvi-xxx.

43. Kademani, B. S.; Kumbar, B. D. and Surwase, G. (2008). Informetric Portrait of Dr C R Karisiddappa: A Professor par excellence. In Library and Information Science Profession in the Knowledge Society, New Delhi, Allied: pp. 45-49.

44. Kademani, B. S.; Surwase, G. and Vijai Kumar (2009). Bhabha Scattering: A Scientometric View. DESIDOC Journal of Library & Information Technology. Vol. 29 (4): pp. 3-11.

45. Kalyane, V. L. and Kademani, B. S. (1995). Scientometric portrait of R. Chidambaram: A publication productivity analysis. Journal of Information Sciences. Vol. 5 (3): pp. 101-140.

46. Kalyane, V. L. and Sen, B. K. (1996). Scientometric portrait of Nobel laureate Pierre-Gilles de Gennes. Malaysian Journal of Library and Information Science. Vol. 1(2): 13-26.

47. Kalyane, V. L. and Kademani, B. S. (1997). Scientometric portrait of Barbara McClintock: The Nobel laureate in physiology. Kelpro Bulletin. Vol. 1(1): pp. 3-14.

48. Kalyane, V. L.; Madan, V. K. and Vijai Kumar. (2001). Reference curve for Indian role model scientist. Malaysian Journal of Library & Information Science. Vol. 6: pp. 57-70.

49. Kalyane, V. L. and Sen, B. K. (2003). Research productivity of Tibor Braun: an analytical chemist-cum-scientometricians. Annals of Library and Information Studies. Vol. 50 (2): pp. 47-61.

50. Koganuramath, M. M.; Angadi, M.; Kademani, B. S.; Kalyane, V. L.; Jange, S. (2004). Physics Nobel Laureate Wolfgang Ketterle: A Scientometric Portrait. Malaysian Journal of Library & Information Science. Vol. 9 (2): pp. 35-61.

51. Kragh, H. (1990). Dirac Bibliometrics. In: Dirac: A scientific biography. Cambridge University, Cambridge: pp. 293-301.

52. Lancaster, F. W.; Zeter, Mary Jo and Metzler Laura. (1992). Ranganathan's Influence Examined Bibliometrically. Libri. Vol. 42 (3): pp. 268-281.

53. Lancaster, F. W.; Bushur, Susan and Man Low, Yuen. (1993). Kochen's Influence examined Bibliometrically. Library Trends: pp. 549-566.

54. Lancaster, F. W. (1991). Bibliometric methods in assessing productivity and impact of research. Sarada Ranganathan Endowment for Library Science, Bangalore

55. Laharia, S .N. and Singh, Y. P. (1987). Scientific productivity measurement. Productivity. Vol. 18: pp. 57-64.

56. Lawani, S. M. (1977). Citation analysis and the quality of scientific productivity. Bioscience, Vol. 27: pp. 26-31.

57. Liu, M. (1993). The complexities of citation practice: A review of citation studies. Journal of Documentation. Vol. 49 (4): pp. 470-408.

58. Mabe, M. A. and Amin, M. (2002), Dr. Jekyll and Dr. Hyde: Author-reader asymmetries in scholarly publishing. ASLIB Proceedings. Vol. 54 (3): pp. 149-157.

59. Mac Roberts, M. H. and Mac Roberts, B. R. (1989). Problems of citation analysis: A critical review. Journal of American Society for Information Science. Vol. 40 (5): pp. 342-349.

60. Mahajan, B. S. (1993). The measure of science and scientists. Current Science. Vol. 65 (7): 511-512.

61. Martin, B. R. and Irvin, J. (1983). Assessing basic research: some partial indicators of scientific progress in radio astronomy. Research Policy. Vol. 12: pp. 61-80.

62. Martyn, J. (1975). Progress in documentation: Citation analysis. Journal of Documentation. Vol.31 (4): pp. 290-297.

63. Moed, H. F. and Vriens, M. 1989. Possible inaccuracies in citation analysis. Journal of Information Science. Vol. 15: pp. 95-107.

64. Moravcsik, M. J. (1973). Measures of scientific growth. Research Policy. Vol. 2: pp. 266-275.

65. Moravcsik, M. J.; Murugesan, P. and Shearer E. (1976). An analysis of citation patterns in Indian Physics. Science and Culture. Vol. 42 (6): pp. 295-301.

66. Muddiman, Dave (2003). Red information Scientist: The information career of J.D. Bernal. Journal of Documentation. Vol. 59 (4): pp. 387-409.

67. Narin, F. (1976). Evaluative Bibliometrics: The use of publication and citation analysis in the evaluation of scientific activities. New Jersey: Computer Horizons, Inc.

68. Narin, F.; Carpenter, M. P. and Woolf, P. (1983). Technological performance assessments based on patents and patent citations. IEEE Transactions on Engineering Management. Vol. EM-31 (4): pp. 172-183.

69. Parthasarathy, P. (2003). Paths of innovators in science, engineering and technology. Vol.2. Chennai, East West Books: pp. 82-86.

70. Penney, L. (1967). Homi Jehangir Bhabha. In: Biographical Memoirs of Fellows of the Royal Society, London. Vol.13: pp. 35-55.

71. Ruff, I. (1979). Citation analysis of a scientific career: A case study. Social Studies of Sciences. Vol. 9: pp. 81-90.

72. Rousseau, R. (1995). Suggestion for research topics in citations and publication analysis. Library Science with a slant to Documentation and Information Studies. Vol. 32: pp. 3-12.

73. Rushton, J. Philippe (2001). A scientometric appreciation of H.J. Eysenck's contributions to psychology. Personality and Individual

Differences. Vol. 31: pp. 17-39.

74. Sandison, A. (1989). Thinking about citation analysis. Journal of Documentation. Vol. 45: pp. 59-64.

75. Sangam, S. L.; Savanur, Kiran; Manjunath, M. and Vasudevan, R. (2006). Scientometric portrait of Prof. Peter John Wyllie. Scientometrics. Vol. 66: pp. 43-53.

76. Sen, S. K. and Gan, S. K. (1990). Biobibliometrics: Concept and application in the study of productivity of scientists. International Forum on Information and Documentation. Vol. 15 (3): pp. 13-21.

77. Sharma, H. P. and Sen, B. K. (2005). Non-citing to an Indian paper in Superconductivity. Current Science. Vol. 88 (12): pp. 1875-1876.

78. Shockley, W. (1957). On the statistic of individual variations of productivity of research laboratories. Proceedings of the IRE: pp. 279-290.

79. Small, H. and Greenlee, E. (1979). A citation and publication analysis of U. S. Industrial Organisations. ISI, Philadelphia.

80. Smith, L. C. (1981). Citation analysis. Library Trends. (Summer): pp. 83-106.

81. Sri Kantha. (1996) Scientific productivity of Einstein, Freud and Landsteiner. Medical Hypotheses. Vol. 46: pp. 467-470.

82. Stern, R. E. (1990). Uncitedness in the biomedical literature. Journal of the American Society for Information Science. Vol. 41 (3): pp. 193-196.

83. Subbarayappa, B. V., Ed. (2007). Science in India-Past and Present, Nehru Centre, Mumbai

84. Swarna, T.; Kademani, B. S.; Kalyane, V. L. and Vijai Kumar (2009). Homi Jehangir Bhabha: A scientometric perspective. Remembering Dr.

Homi Bhabha, The physicist, Bhabha Atomic Research Centre, Mumbai: pp. 42-56.

85. Taube, G. (1993). Measure for measure in science. Science. Vol. 260: pp. 884-886.

86. Tiew and Wai Sin. (1999). Khoo Kay Kim, Professor of Malaysian History: A Bibliometric Study. Malaysian Journal of Library & Information Science. Vol. 4 (2): pp. 47-57.

87. TIFR Library. (1980). Collected Papers and speeches of H. J. Bhabha. Vol. 1-2, TIFR, Mumbai.

88. Todorov, R. and Winterhager, M. (1991). An overview of Mike Moravcsik's publication activity in physics. Scientometrics. Vol. 20: pp. 163-172.

89. Van Dalen, H. P. and Henkens, K. (2005). Signal in science-on the importance of signaling in gaining attention in science. Scientometrics. Vol. 64 (2): 209-233.

90. Venkataraman, G. (1994). Bhabha and his magnificent obsession, Hyderabad, University Press.

91. Wadia, S. R. (2009). Homi Jehangir Bhabha and the Tata Institute of Fundamental Research. Current Science. Vol. 96 (5): pp. 725-733.

92. Wallmark, J. T. and Sedig, K. G. (1986). Quality of research measured by citation method by peer review-a comparison. IEEE Transactions on Engineering Management. Vol. EM-33 (4): pp. 218-222.

A Sketch by H.J. Bhabha

Published by :
Dr. Vijai Kumar
Associate Director, Knowledge Management Group and
Head, Scientific Information Resource Division
Bhabha Atomic Reserarch Centre
Mumbai 400 085, India